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ON THE DETECTION OF FISH-GROUPS BY AN ACOUSTIC METHOD.

By

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§ In the similar method as in the Sonic-Depth-Finder, we will be able to detect fishes by sonic method. When sonic waves are emitted from a projector, they are reflected and absorbed by fishes on the propagating course of waves and are reflected and refracted by the turbulence of water owing to the motion of fishes. The transmitted waves may consequently be changed in their intensity, frequency and wave-form.

§ To see whether the detection of fishes may be possible or not, the writer made experiments, last summer, in the ponds of Ootyô Fish-Cultural Station, Pref. Hirosima.

Method and Apparatus: The electric oscillations of 200,000 cycles modulated with 1,000 cycles are generated in the oscillating circuit of the transmitting set,(1) and they are, by the projector of quartz condenser, transformed into ultra-sonic waves of 200,000 cycles modulated with sonorous waves of 1,000 cycles—the frequency at which the human ear has maximum sensitiveness. The ultra-sonic waves, instead of producing an emission which spreads in every direction, will find themselves confined to a sort of cone and the emission will occur with maximum intensity in a direction perpendicular to the plane of the source; and for the sake of convenience, we call this direction, the direction of the quartz condenser. By another quartz condenser, the waves are received and transformed into electric oscillations in the oscillating circuit of the receiving set.(2) Then the oscillation current is amplified and, by a telephone receiver, we observe the amplified crrent which is called, in this paper, the receiving current.

§ Experiment I, Case A.

Size of the pond used : $43^m \times 28^m$.
Depth of ,, ,, ,, : $1.5^m - 4.5^m$.
Fish-group used : 20–30 "*Pagrosomus major* T. & S." ($40^{cm} - 50^{cm}$).

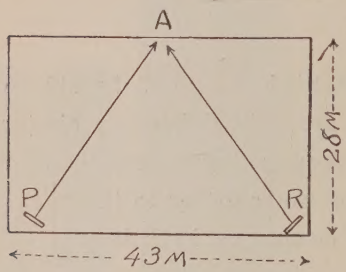
(1) & (2): The transmitting and the receiving sets were prepared at Andow Laboratory.

Extension of the group :* 3^m-5^m long, 1^m-2^m wide.

Speed of ,, ,, : $45^{cm}/_{sec.}$ (mean value).

Besides this group, about 50,000 fry of "*Pagrosomus major* T. & S." (about 4 cm.) were nearly uniformly distributed along the sides of the pond.

Fig. 1.



The projector *P* (Fig. 1) and receiver *R* (Fig. 1) of quartz condensers were put in water at the depth of about 30 cm. and the direction of the projecter and receiver was adjusted in such a way that the sonic waves projected from the projector and reflected at the side *A* (Fig. 1), might arrive at the receiver and that the receiving current might have the maximum intensity.

When a fish lies on the path *PAR* (Fig. 1), the received sound is weakened in consequence of reflection and absorption of the fish-body. But as usually only a part of the projected waves is received by the receiver, the received sound may be strengthened when the waves, which otherwise do not arrive at the receiver, are reflected by fish-bodies to arrive at the receiver. So the sound received by the receiver is weakened and strengthened when a fish-group crosses the path *PAR* (Fig. 1). Hence we can detect the group by examining the change of the receiving current.

In Exp. I, the projector and receiver were put in the depth of 30 cm. and the direction of these quartz condensers was horizontal : so a part of the sonic waves was reflected by the surface of water. Consequently, the waves on the surface of water could change the receiving current. But Exp. I and II were done only when there were no waves on the surface of water.

The oscillographic record of the receiving current, taken when the fish-group crossed the path *PAR* (Fig. 1) just in front of the receiver, is shown in PL. I. Similar records were obtained, when it crossed the path at other points. In the record of PL. I, we see that the time interval of one change in the intensity of the receiving current is about a second.

When a fish of length L passes in front of the receiver of quartz condenser of breadth l, with speed V, the time interval T of one change of the receiving current is calculated as follows:

* By extension of the group, the writer means the extension of the space occupied by that group.

$$T=\frac{L+l}{V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

In the present case, $L=45$ cm, $V=45\,^{cm}/_{sec}$ and $l=4.0$ cm. Hence

$$T=1.1 \text{ sec.}$$

Further, in the record of PL. I, we see that a change of higher frequency, of many tens of cycles, is continously superposed upon the receiving current. This change of higher frequency may be caused by the fry because it is not found in the records taken when fry were *not uniformly* distributed in the pond.

The detectability, D, of fish-groups by a telephone receiver is calculated by the equation (2),

$$D=\frac{n_1}{n_1+n_2+n_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

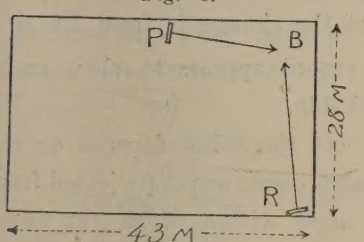
where n_1: no. of cases when fish-groups could be detected positively,

n_2: no. of cases when fish-groups could not be detected,

n_3: no. of cases when changes due to other unknown causes were mistaken for the pass of fishes.

The values of n_1, n_2 and n_3 in the present case, Exp. I, Case A, were obtained as follows:

Fig. 2.



$n_1=28$,

$n_2=7$,

$n_3=1$,

and $D=78\,\%$.

Case B. Next, the position of the projector and receiver was changed as shown in Fig. 2. Even in this position, feeble sound could be received owing to multiple reflection by the boundary. A large number of fry (about 50,000) was uniformly distributed along the sides of the pond and therefore, along the line PB in Fig. 2, the fry were densely distributed. Hence, in this case, Case B, the intensity of the feeble sound of 1,000 cycles was changed with the frequency of many tens of cycles owing to the existence of the distributed fry This change due to the distributed fry could easily be heard by a telephone receiver. When the group of larger fishes approaches to the vicinity of B, the receiving current may be intensified because a part of the sound reflected by the fishes arrives at R. In fact, in the records taken when the group approaches to the vicinity of B, the changes just stated are found and we see that the change of the receiving current due to the group of larger fishes

is nearly a periodic vibration having a period of about $\frac{1}{3}$ sec.

In Case B, the values of n_1, n_2 and n_3 in the equation (2) are shown as follows:

$$n_1=19, \quad n_2=13, \quad n_3=10,$$

and $D=45\,\%$.

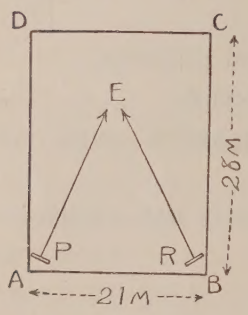
§ Experiment II.

Size of the pond used : $28^m \times 21^m$.

Depth of ,, ,, ,, : 4^m.

Fish-group used : $900 (15^{cm}-18^{cm})$ and $2000 (4^{cm}-5^{cm})$ "*Sparus latus* Houttuyn."

Fig. 3.



These fishes were swimming about very slowly near the side *CD* (Fig. 3).

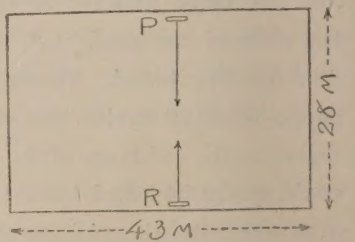
The quartz condensers *P* and *R* (Fig. 3) were dipped at the depth of about 1.5 meters in the direction *PE* and *RE* as shown in Fig. 3.

Then the receiving current is intensified as a part of reflected sound arrives at the receiver when the fishes come to the vicinity of E.

The oscillographic record PL. II taken in Exp. II, shows that the duration of the change is from 1/6 to a few seconds. Besides these changes, the same record appears to show many changes of shorter duration which are not remarkable.

§ The range of space in which we can detect the fishes depends on the 'projecting angle'—the angle of divergence of the ultra-sonic waves projected from the projector—and on the 'receiving angle'—the angle within which the waves arriving at the receiver can give an effective stress to the quartz plates of the receiver. As shown in Fig. 4, setting the direction of the projector *P* perpendicular to one side of the pond, setting the receiver *R* opposite to *P* and rotating *R* about its vertical axis, the writer determined the receiving angle of the receiver by examining the relation of the intensity of the receiving current to the rotating angle of *R*. In order to determine the projecting angle of *P*, *P* was rotated about its vertical axis and the relation of the intensity of the receiving current to the rotating angle of *P* was measured. Owing to the reflection of sound by the

Fig. 4.



boundary and the slow change of the electric condition in the transmitting and receiving sets, etc., the observed values were not accurate. The writer obtained the range from 14° to 24° (in plane angle) for the both values of the 'projecting and receiving angles.'

R. B. Lindsay* calculated the intensity of high frequency sound radiation from a circular piston-like vibrator and obtained the result that the most of sound energy is contained in a cone of solid angle $\pi\left(0.45\frac{\lambda}{a}\right)^2$ ster radians, where λ is the wave length of the radiation and a is the radius of the vibrator. Then the plane diverging angle δ is expressed by

$$\delta = 2 \text{ arc tan } \left(0.45\frac{\lambda}{a}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

In our experiments, the frequency of radiation is 200,000 and the area of the vibrator 4.0 cm. square, so we have $\lambda = 0.73$ cm. and $a = 2.0$ cm, assuming that the breadth corresponds to the diameter of the circular piston-like vibrator. Putting these values of λ and a in the equation (3), we obtain

$$\delta = 18.5° \quad .$$

Before closing this paper, the writer expresses his glatitude to Dr. M. Tanti under whom the work was carried out and to Mr. K. Isii and Mr. K. Hasizume for assistance during the course of the experiments. He also expresses his best thanks for the kindness of Mr. E. Kajiyama who is in charge at the Ootyô Fish-Cultural Station.

Summary.

Ultra-sonic waves of 200,000 cycles modulated with sonorous waves of 1,000 cycles are projected in water from a quartz condenser. The waves are reflected and absorbed by fishes on the propagating course of sound and are reflected and refracted by the turbulence of water due to the motion of fishes. So that the transmitted waves may be changed in their intensity, frequency and wave-form according to the condition whether there are fishes on the propagating course of sound or not. When we receive the waves by another quartz condenser, we can detect fish-groups by examining the change of the current in the receiving set. By this method, 50-80 % of groups could be detected in the ponds used in the experiments, and in the case when there were no waves on the surface of water in the ponds.

Spet. 1928. Physical Laboratory, Imp. Fish. Institute, Tôkyô

* R. B. Lindsay, Phys. Rev. 32, 515 (1928).

A STUDY ON BRINE FREEZING OF FISHES.

By

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Recently, Mr. Zempei Ogura and Mr. Kiyoshi Fujikawa[1] published a report of experiments on the refrigeration of fishes. In the present paper some theories of refrigeration of fishes are verified with the experimental results obtained by those authors.

1. In the case of freezing a fish, let $-\theta$ be the temperature ; μ, the specific weight of fish-body ; k, the thermal conductivity ; and q, the heat quantity taken away from a unit mass of fish. Then the thermal equation at any point, (x, y, z), taken within a fish-body at time t, is

$$\frac{\partial}{\partial x}\left(k\frac{\partial\theta}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial\theta}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial\theta}{\partial z}\right)=\frac{\partial\mu q}{\partial t}. \quad \ldots\ldots\ldots\ldots (1)$$

The bodily-juice of fish is a kind of solution, of which the eutectic point is said to be about –30° C. At temperatures higher than this eutectic point, fish-body is not in a fully frozen state and a certain quantity of bodily-juice remains in liquid state even in frozen muscles. In such a case the temperature at any point in frozen muscles coincides with the freezing point of the solution remaining in the muscle and is therefore a function of its concentration. The concentration is inversely proportional to the quantity of water, ρ, remaining in liquid state in a unit volume of the muscle. (In the present case, the change of pressure within fish-body, the change of specific volume of the muscle, the effect of diffusion of solute in the bodily-juice, the capillary effects and osmose are neglected). Thus the temperature is uniquely determined by the ratio, r, of the quantity of ice produced, $\rho_0-\rho$, to the original quantity of water, ρ_0, and in turn the ratio, r, by temperature, *i. e.*

$$r=\frac{\rho_0-\rho}{\rho_0}=\psi(\theta).$$

The thermal conductivity , k, and the specific heat of fish-body are functions of r and θ, and therefore they are functions of θ. Denoting the heat of freezing of water by $L(\theta)$ and the specific heat of fish-body by $c(\theta)$, we have

1) Zempei Ogura and Kiyoshi Fujikawa: On the Refrigeration and Preservation of Fishes. Bulletin Govern. Fish. Exp. Stat. Chosen. No. 1. (1925), in Japanese with English abstract.

$$\mu q = \int_0^r L(\theta)\rho_0 dr + \int_{\theta_{t=0}}^{\theta} c(\theta)\mu d\theta,$$

or denoting the freezing point of fish-muscle by θ_0, we have

$$\mu q = \rho_0 \int_{\theta_0}^{\theta} L(\theta)\psi'(\theta)\,d\theta + \mu \int_{\theta_{t=0}}^{\theta} c(\theta)\,d\theta. \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Putting $\rho_0 L(\theta)\psi'(\theta) + \mu c(\theta) \equiv F(\theta)$, and $k = k(\theta)$, we get the differential equation of θ from the equation (1) :—

$$\frac{\partial}{\partial x}\left(k(\theta)\frac{\partial\theta}{\partial x}\right) + \frac{\partial}{\partial y}\left(k(\theta)\frac{\partial\theta}{\partial y}\right) + \frac{\partial}{\partial z}\left(k(\theta)\frac{\partial\theta}{\partial z}\right) = F(\theta)\frac{\partial\theta}{\partial t}. \quad \ldots\ldots\ldots\ldots (3)$$

The fishes of same species in the same condition have a shape similar in geometrical meaning. They contain the same quantity of solution of the same quality per unit volume. Hence for such fishes the quantities, θ_0, μ and ρ_0, as well as the functional forms of the functions, $\psi(\theta)$, $c(\theta)$, $k(\theta)$ and $F(\theta)$, are the same. Take two of such fishes and call each one of them respectively by the name of the 'first' fish and the 'second' fish. Let the size of these two fishes be indicated by the lengths l_1 and l_2. Next suppose a point, (x_1, y_1, z_1), in the first fish and a point, (x_2, y_2, z_2) 'corresponding' to it, in the second, in the geometrically similar position. Then the following relations are satisfied :

$$\frac{x_1}{x_2} = \frac{y_1}{y_2} = \frac{z_1}{z_2} = \frac{l_1}{l_2} = L, \ L \text{ being a constant.} \quad \ldots\ldots (4)$$

By the 'corresponding' time, let us mean a time, t_1, considered for the first fish, and a time, t_2, 'corresponding' to it for the second, taken so as to keep the relation :

$$t_1 = Tt_2, \quad T \text{ being a certain constant.} \quad \ldots\ldots\ldots\ldots (5)$$

and at the same time, if possible, to satisfy the condition that, at the 'corresponding' time the relation between the temperature, θ_1, of the first fish and that, θ_2, of the second at the 'corresponding' points is always given by the following equation :

$$\theta_1 = \Theta\theta_2, \quad \Theta \text{ being a constant.} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

This condition is satisfied if the thermal equation, (3), for one of the two fishes become identical with that for the other when we substitute the relations (4), (5) and (6) into that equation. In order that the relation, $F(\theta_1) = F(\Theta\theta_2) \equiv F(\theta_2)$ may be satisfied, we must have $\Theta = 1$, or $\theta_1 = \theta_2$. If $\theta_1 = \theta_2$, we have

$$\frac{\partial}{\partial x_1}\left(k(\theta_1)\frac{\partial \theta_1}{\partial x_1}\right)+\frac{\partial}{\partial y_1}\left(k(\theta_1)\frac{\partial \theta_1}{\partial y_1}\right)+\frac{\partial}{\partial z_1}\left(k(\theta_1)\frac{\partial \theta_1}{\partial z_1}\right)-F(\theta_1)\frac{\partial \theta_1}{\partial t_1}$$

$$=\frac{1}{L^2}\left\{\frac{\partial}{\partial x_2}\left(k(\theta_2)\frac{\partial \theta_2}{\partial x_2}\right)+\frac{\partial}{\partial y_2}\left(k(\theta_2)\frac{\partial \theta_2}{\partial y_2}\right)+\frac{\partial}{\partial z_2}\left(k(\theta_2)\frac{\partial \theta_2}{\partial z_2}\right)\right\}-\frac{1}{T}F(\theta_2)\frac{\partial \theta_2}{\partial t_2}.$$

Hence the condition required is satisfied if we have

$$\Theta=1, \quad \text{and} \quad T=L^2.$$

Strictly speaking, when and only when the temperatures at the ' corresponding ' points become the same, there is a ' corresponding ' time, and the ' corresponding' time, t, is proportional to the square of the length, l, indicating the linear dimension of the size of fish-body.[1]

$$t \propto l^2. \quad \ldots\ldots\ldots\

Table I.

t: Time (in min.); $2l$: height of the cross-section of trunk (in *sun*[1]); q: "cold quantity" (in gram-cal./gram.); $-\theta_e$: temperature of medium (brine) (in °C), v: velocity of circulation of the medium (in inches/min.); d: depth of freezing layer of muscles (in *sun*); (*: frozen completely).

a. Mackerels $\theta_e=13$

t	$v=0$			$v=30$		
	$2l$	d	q	$2l$	d	q
	—	0.30	13.5	2.40	0.20	14.8
20	1.9	0.40	29.7	2.60	0.40	20.8
	1.75	0.45	28.1	2.45	0.30	21.4
	2.40	0.50	25.4	2.30	0.50	30.1
40	2.10	0.50	40.4	2.60	0.50	37.9
	2.31	0.81	45.1	2.00	0.60	35.3
	2.70	0.70	31.9	2.50	0.50	26.1
60	2.60	0.70	29.7	2.70	0.70	30.3
	2.00	0.95	38.0	2.50	0.90	42.5
	2.70	0.90	40.9	2.70	0.50	25.1
80	2.20	*	54.3	2.50	*	48.8
	2.50	*	48.8	2.60	*	39.4
	2.40	*	47.8	2.50	*	38.3
100	2.40	*	52.3	2.50	*	48.7
	2.65	*	50.5	2.30	*	43.4
	2.60	*	45.7	2.40	*	43.2
120	2.40	*	57.7	2.60	*	44.7
	2.35	*	54.9	—	*	48.9
				2.40	*	49.3
140				2.60	*	50.3
				2.15	*	51.6
				2.40	*	41.6
160				2.40	*	43.4
				2.50	*	41.2

b. Mackarels $\theta_e=8$

t	$v=0$			$v=30$		
	$2l$	d	q	$2l$	d	q
	2.30	0.30	9.1	2.50	2.0	19.6
20	2.50	0.25	—	2.50	2.0	12.0
	2.60	0.00	6.8	2.50	2.0	13.3
	2.30	0.40	19.1	2.40	3.0	18.0
40	2.50	0.30	—	2.70	5.0	20.6
	2.25	0.45	17.7	2.20	2.0	23.1
	2.60	0.50	19.6	2.50	4.0	18.0
60	2.60	0.26	—	2.50	4.0	19.0
	2.20	0.55	30.7	2.85	3.5	17.5
	2.50	0.60	34.8	2.60	5.0	23.1
80	2.50	0.60	—	2.60	5.0	18.7
	2.60	0.60	32.7	2.65	5.0	30.4
	2.50	0.80	26.0	2.10	5.0	24.3
100	2.50	0.60	—	2.80	7.0	22.6
	2.25	0.70	37.9	2.70	6.0	19.2
	2.50	0.90	27.8	2.70	*	26.0
120	2.50	0.80	—	2.40	7.0	35.0
	2.35	*	44.1	2.45	*	28.6
	2.30	*	35.2	2.50	*	40.0
140	2.50	0.90	—	2.50	*	32.7
	2.55	*	27.1	2.45	*	25.4
	2.40	*	47.0	2.40	*	43.6
160	2.70	*	—	2.50	*	50.7
	2.05	*	30.5	2.65	*	43.4
	2.40	*	34.0	2.60	*	37.6
200	2.60	*	—	2.60	*	49.4
	2.35	*	41.6	2.50	*	40.3
				2.30	*	41.8
240				2.80	*	31.7
				2.50	*	36.7
	2.60	*	39.0	2.60	*	41.8
300	2.50	*	—	2.80	*	38.6
	—	*	33.8	2.70	*	35.2
	2.55	*	40.5	2.50	*	39.8
24 × 60	2.30	*	—	2.40	*	39.1
				2.40	*	39.9

1) In the present paper, the unit of length is throughout 1 *sun* $\left(=\frac{10}{3.3}\text{ cm.}\right)$

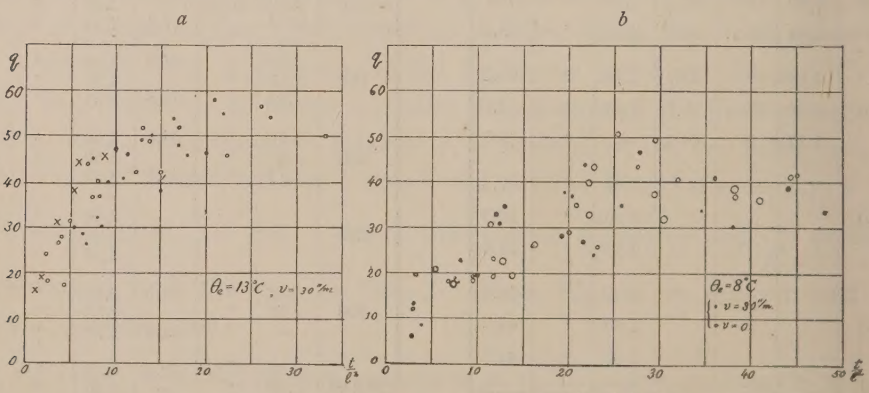
c. Herrings $\theta_e=13$, $v=30$

t	$2l$	d	q
	2.00	0.40	18.0
10	2.05	0.25	23.6
	2.40	—	20.2
	2.20	0.40	27.7
20	2.30	0.50	26.5
	1.90	0.50	39.8
30	2.00	0.50	36.5
	2.45	0.60	31.3
	2.40	*	44.0
40	2.20	*	36.6
	2.10	*	46.0
50	1.50	*	45.7
	1.90	*	49.1
	2.50	*	47.2
60	2.20	*	42.4
	2.15	*	52.4
	2.30	*	41.7
80	2.00	*	46.4
		*	
	2.10	*	54.4
120	2.15	*	56.6
	1.90	*	50.1

d. Yellow-tails $\theta_e=13$, $v=30$

t	$2l$	d	q
30	5.00	0.40	10.2
1×60	5.50	0.80	19.1
2×60	5.70	1.00	30.7
3×60	5.70	1.40	38.2
4×50	6.40	1.60	44.3
5×60	5.80	*	45.9
6×60			

Fig. 1.



Size of marks (in *b*) represents the size of fishes (mackerels). Heat-quantity, q, is a definite function of $\frac{t}{l^2}$. This function (in *a*) is nearly same for yellow-tails, ○; mackerels, •; and herrings, ×.

In order to calculate the numerical value of q for a given temperature, we must determine the functional forms of the functions appearing in the expression (2). When θ, measured so as to give $\theta=0$ at 0° C, is not very great, we can put

$$L(\theta)=L_0-\alpha\theta, \text{ where } L_0=80\,\text{gr. cal.}, \quad \alpha=0.615\,\text{gr. cal./° C}^{1)},$$

and, according to Rault's law of depression of freezing point of a solution, we have

$$(1-\gamma)=\frac{\rho}{\rho_0}=\frac{\theta_0}{\theta}, \quad \therefore \quad \psi'(\theta)=\frac{\theta_0}{\theta^2}. \quad \ldots\ldots\ldots\ldots(8)$$

The specific heat of the fish-muscle, $c(\theta)$, is mainly due to that of ice, c', and to that of liquid water, c, and we can put

$$\mu c(\theta)\fallingdotseq\rho_0\{c(1-\gamma)+c'\gamma\}=\rho_0(c-c')\frac{\rho_0}{\theta}+\rho_0 c', \qquad \text{for } \theta\geqq\theta_0,$$

and $$\mu c(\theta)\fallingdotseq\rho_0 c \qquad , \qquad \text{for } \theta_0\geqq\theta\geqq 0.$$

Carrying out the integrations in the expression (2), where $\rho_{t=0}=0$, we obtain

$$\frac{\mu}{\rho_0}q\fallingdotseq L_0\theta_0\left(\frac{1}{\theta_0}-\frac{1}{\theta}\right)+(-\alpha+c-c')\theta_0 ln\frac{\theta}{\theta_0}+(c-c')\theta_0+c'\theta. \quad \ldots\ldots(9)$$

When by means of this formula we calculate the "cold quantity", Q, for the final state of freezing, in which the temperature of fish-body becomes equal to that of the surrounding medium, and plot the relation between $\log(Q-\bar{q})$ and $\frac{t}{l^2}$ in a graph, we know that this relation is represented as a straight line:

$$\log(Q-\bar{q})=\log Q-\eta\frac{t}{l^2}\log e, \qquad \eta \text{ being a constant,} \quad \ldots\ldots\ldots(10)$$

as it is shown in Fig. 2. Hence the relation between $\bar{q}$ and $\frac{t}{l^2}$, given in Fig. 1. is to be expressed by an equation:

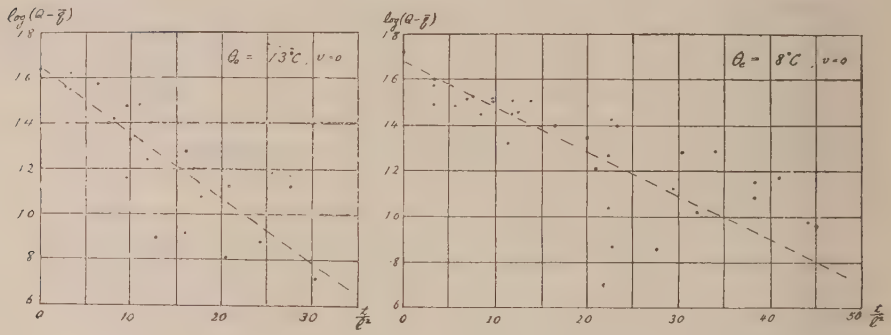
$$Q-\bar{q}=Qe^{-\eta\frac{t}{l^2}}.$$

In calculation of the value of Q, we put, for mackerels, $\frac{\mu}{\rho_0}=0.725$, and $-\theta_0=-1.5$° C. The value of θ_0 was determined from the freezing-curves of mackerels previously obtained by S. Ogawa[2)] and Y. Monuki (Fig. 3).

1) Calculated from the values of $L(\theta)$ given by Petterson.

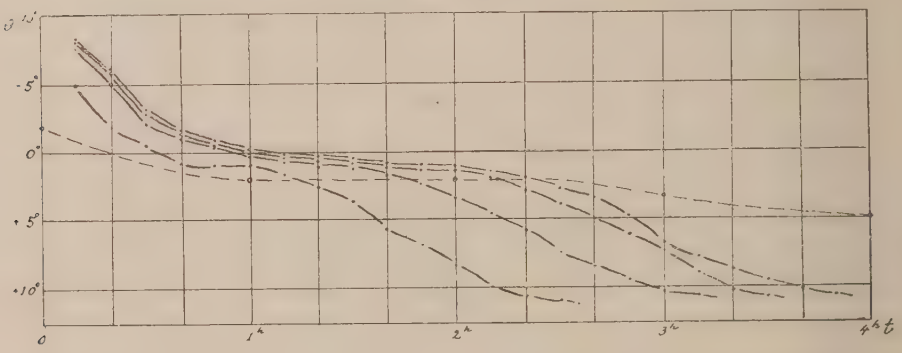
2) S. Ogawa: J. Imp. Fish. Inst. Vol. XVIII, No. 4, p.p. 12~20, (1925), in Japanese.

Fig. 2.



Relation between $\bar{q}$ and $\frac{t}{l^2}$ (Fig. 1) is exponential because the relation in this figure is linear.

Fig. 3.



The value of θ_0 ($-1.5°$ C for mackerels) is determined from these freezing-curves obtained by S. Ogawa —○— (air at $-22°\sim-20°$ C) and by Y. Momuki —•— (brine at $-12.5°$ C). t: time in hours.

2. Imagine a body of fish divided into layers, having the surfaces which are similar and similarly situated to the external surface of fish. Consider that the freezing state of a definite degree proceeds layer by layer from the external surface toward the centre of the body. Let λ be a length indicating the linear dimension of one of the surfaces given above, and consider a layer between two surfaces corresponding to the lengths $\lambda \pm \frac{1}{2} d\lambda$. The volume between these two surfaces and the surface area of the λ-surface are given in the forms: $V\lambda^2 d\lambda$ and $S\lambda^2$ respectively, where V and S are constants. In the case of fish previously kept at 0° C by putting it in ice, the distribution of temperature in the fish-body, at the instant when this λ-layer just begins to freeze, may be in such a state

that, in the inner portion enclosed by this λ-layer the temperature is nearly uniform, while outside this layer there is a gradient of temperature. After a short interval of time, δt, the temperature of λ-layer becomes $-(\theta_0+\delta\theta)$, and the adjacent $(\lambda-\delta\lambda)$-layer begins to freeze. In this interval of time, a heat quantity given by $F(\theta_0)\, V\lambda^2\, d\lambda\, \delta\theta$ is taken away from the λ-layer and that given by $k(\theta_0)\left(\frac{\partial\theta}{\partial l}\right)_{\theta=\theta_0} \times S\lambda^2\delta t$ is transferred from λ-layer to the outer portion. The quantity of heat transferred from the inner portion to λ-layer may be negligible, and the two quantities given above are equal to each other. Seeing that $\frac{\delta\theta}{\delta\lambda}=\left(\frac{\partial\theta}{\partial\lambda}\right)_{\theta=\theta_0}$ we come to conclusion that this relation gives

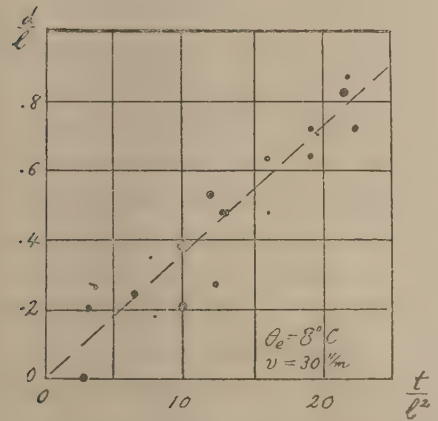
$$\delta\lambda \propto \delta t,$$

i. e. the thickness of the freezing layer increases uniformly.

Taking two fishes of the same sort, let l_1 and l_2 be the lengths indicating the sizes and d_1 and d_2 be the thickness of the frozen layers. Then at times, t_1 and t_2, when $\frac{d_1}{l_1}=\frac{d_2}{l_2}$, the distribution of temperature in fish-bodies may be similar, and t_1 and t_2 is the 'corresponding' times, *i. e.* $\frac{t_1}{l_1^2}=\frac{t_2}{l_2^2}$. Consequently we obtain the relation :

$$\frac{d}{l} \propto \frac{t}{l^2}.$$

Fig. 4.



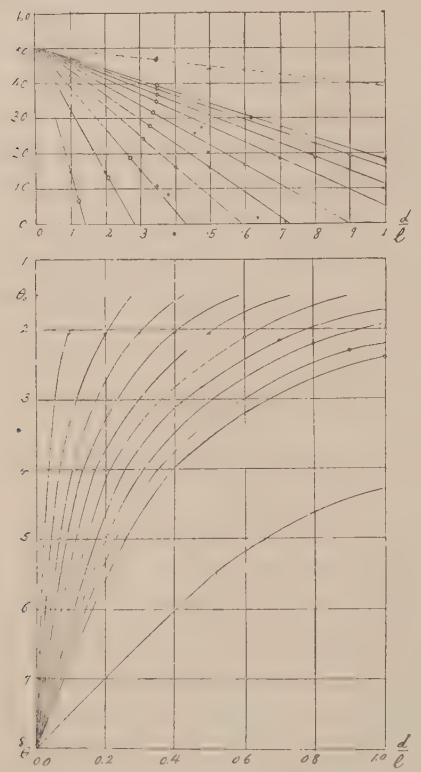
Size of marks represents the size of fish (mackerel). Relation between $\frac{d}{l}$ and $\frac{t}{l^2}$ is independant of l. Thickness, d, of freezing layer increases uniformly.

An example of the relation between $\frac{d}{l}$ and $\frac{t}{l^2}$ calculated from the experimental data given in Tab. I, is shown in Fig. 4. Of course the thickness of the layer frozen in theoretical meaning can not be measured and d in Fig. 4 represents the thickness of recognizable freezing layer. But both values of d may vary in a parallel manner.

3. Because of the difficulty of solving the equation (3) under the given initial and boundary conditions, let us assume that q is a linear function of the lengths, λ, which indicate the linear dimensions of those similar and similarly

situated surfaces considered in the preceeding paragraph. Then, the distribution of q is uniquely determined by two entities, *e.g.* the value of q at any point on the external surface of fish-body and the mean value of $q, \bar{q}$, in a round slice. Taking the former as equal to Q in the equation (10), and calculating the latter from the same equation, (10), we obtain the distribution of q and that of θ—the latter being calculated by the relation (9)—at the instants when $\frac{d}{l}$ in Fig. 4 was 0.1, 0.2, 0.3, etc., (Fig. 5).

Fig. 5.



Distribution of temperature from the centre $\left(\frac{d}{l}=1.0\right)$ to the external surface $\left(\frac{d}{l}=0.0\right)$ of fish-body, calculated from an assumed distribution of q. ○: mean value of q; ●: extremity of the recognizable freezing layer.

As the first approximation, the assumption of linear distribution of q may be natural from the following points of view.

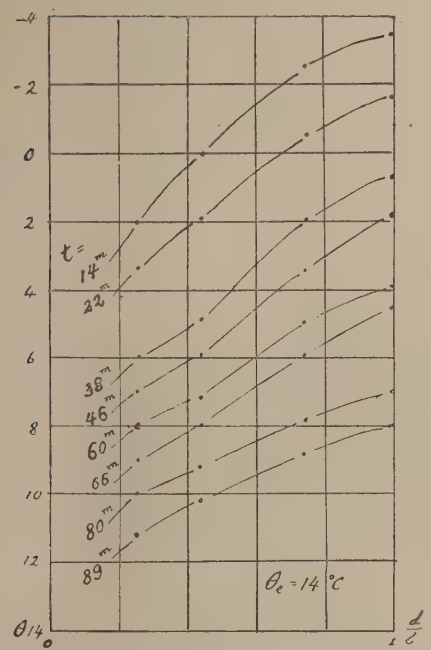
a) The distribution of temperature at the beginning of refrigeration, is such that the gradient is great in the portion near the external surface, and is very small in the interior of fish-body. This will be actually the case.

b) In the region where the value of λ is fairly less than that on the external surface, the temperature at any point on the λ-surface varies as λ varies. In such a region, the gradient of temperature is less at the beginning of refrigeration, it gradually increases and then becomes less again. This coincides with the fact previously observed by Y. Monuki, whose results are given in Fig. 6.

c) When the temperature at a point on the external surface of fish-body is kept constant, the rate of increasing of $\bar{q}$ must be proportional to the gradient of q at the point on the external surface of fish-body. This is nearly satisfied as is seen in Fig. 7.

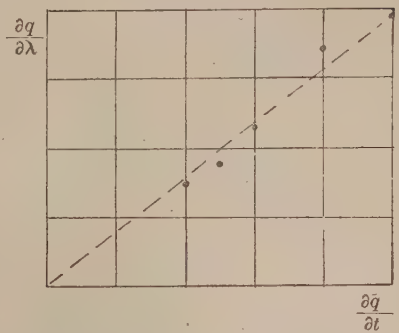
d) Freezing state may be recognizable

Fig. 6.



Distribution of temperature from the centre to the external surface of fish-body, (mackerel), observed by Y. Monuki.

Fig. 7.



Rate of increasing of $\bar{q}$ is proportional to the gradient of q at the external surface of fish-body, the latter being calculated from the assumed distribution of q in Fig. 5.

when the ratio, r, of the quantity of ice to that of water is greater than a definite value. Since $r=\psi(\theta)$ and q is also a function of θ, the values of q and θ must be constant at the extremity of the recognizable freezing layer. In Fig. 5, these values of q and θ are almost constant. Calculating the value of r, by $1-r=\frac{\theta_0}{\theta}$, we obtain $r=0.3\sim0.5$ at the extremity of the recognizable freezing layer.

4. Z. Ogura and K. Fujikawa noticed that when fishes are kept too long in brine, the "cold quantity" may be lessened owing to the penetration of salt, which melts the frozen ice. The authors kept mackerels in brine at $-8°$ C for 24 hours, and measured the value of q of the fishes. They came to conclusion that the loss of q is practically of no importance for the immersion of fish in brine during less than 24 hours or so.

There are various causes to make the actual value of the "cold quantity" differ from the value calculated from the equation (9). Besides the penetration of salt, we may take, as important, the increase of internal pressure in the muscle and the penetration of water into fish-body.

The penetration of salt causes the depression of freezing point of fish-muscle. The amount of depression is given by $\Delta\theta_0=0.583°\,\mathrm{C}\times\frac{\Delta\varepsilon}{\rho_0}\mu$, where $\Delta\varepsilon$ repre-

sents the increment of percentage of salt (common salt) in the muscle. The depression of $-\theta_0$ results in the decrease, Δr, of the ratio of the quantity of ice to the original quantity of water. Δr is given by the relation:

$$\theta=\frac{\theta_0}{1-r}=\frac{\theta_0+\Delta\theta_0}{1-(r+\Delta r)}, \quad \therefore \quad \Delta r=-\frac{\Delta\theta_0}{\theta}.$$

The decrement of the "cold quantity" is

$$\Delta q=L\frac{\rho_0}{\mu}\Delta r.$$

As to the rate of penetration of salt, Z. Ogura and K. Fujikawa made many experiments. Cutting the muscle beneath the external surface of fish-body into a layer having the thickness of 1 *bu* $\left(=\frac{1}{3.3}\text{ cm}\right)$, the authors called it the first layer. The next layer of the same thickness was called the second layer. They determined the percentage of salt in these two layers and obtained the results given in Tab. II and in Fig. 8. The mean percentage, $\bar{\varepsilon}$, is calculated from those

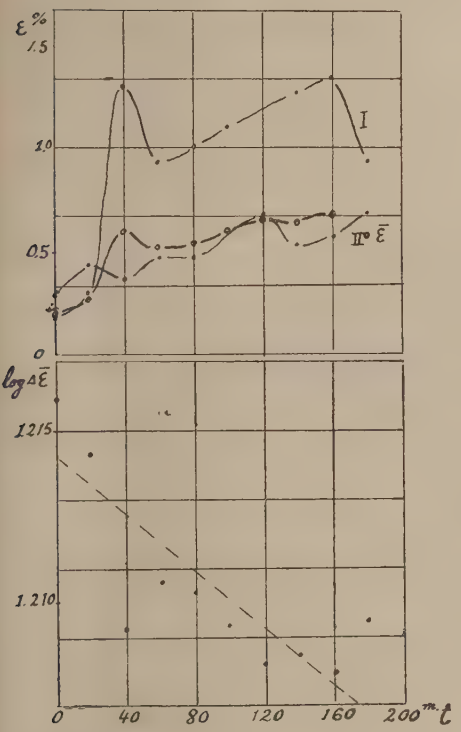
Table II.—Penetration of salt into mackerels.

t: time in minutes; ε_I, ε_{II}: percentage of salt in the 1st and 2nd layers; $-\theta_e$: temperature of medium (brine) in °C.

t	ε_I	ε_{II}	θ_e	t	ε_I	ε_{II}	θ_e
0	0.20	0.34	—	100	1.30 0.98	— 0.80	9.0
20	0.35 0.40	0.50 0.35	10.0	120	— 1.12	0.80 0.80	9.0
40	1.55 1·36	0.42 0.60	10.0	140	1.50 1·30	0.62 0.76	9.0
60	1.10 1.20	0.54 0.70	8.0	160	1.60 1.04	0.60 0.80	9.0
80	1.20 1.00	0.54 0.60	8.0	180	1.11 —	0.80 0.78	9.0

data, assuming that the penetration of salt in the other region of the body was negligible for about 3 hours, which were worked out by the authors. The mean value, $\bar{\varepsilon}$, approaches exponentially to the value of saturation, $\varepsilon'(=16.8\,\%)$, just as in the ordinary diffusion. By extrapolation as seen in Fig. 8, we obtain the increment, $\Delta\bar{\varepsilon}$, of mean percentage after 24 hours. $\Delta\bar{\varepsilon}$ is about 1.6~2.7 %, from which we get the value 1.3° C~2.1° C for $\Delta\theta_0$. Putting $\theta=8$, $L=76$ and $\frac{\rho_0}{\mu}=0.725$, we get $\Delta r=-0.16-\sim0.26$, and $\Delta q=-9\sim-12$ cm. cal./cm². The observed values of q

Fig. 8.



Penetration of salt in the muscle of the outermost layer, I, and the next layer, II, of fishbody. The calculated mean percentage, $\bar{\varepsilon}$, of salt in muscle approaches exponentially to a saturation value and enables us to determine the value of $\bar{\varepsilon}$ after 24 hours by means of extrapolation (bottom).

are 39.1, 39.8, 39.9 and 40.5 (Tab. I), while the value of q calculated from the equation (9) is 50.7. The difference, 10.9, is therefore explainable by the effect of penetration of salt.

In order to examine the effect of penetration of water, let us keep in sight a part of fish-body, which has unit volume initially. If the quantity of water (including ice) increases from ρ_0 to $\rho_0+\Delta\rho_0$, the mass of the part under consideration will change from μ to $\mu+\Delta\rho_0$. Since the concentration of the solution remaining in fish-muscle in liquid state is determinate for any given temperature, we can consider that a definite quantity of ice freezes out from the water originally contained in the muscle whether the penetrated water is added to that part or not, while the whole of the penetrated water freezes. Hence, for the increased "cold quantity", $q+\Delta q$, we can put

$$(\mu+\Delta\rho_0)(q+\Delta q)=L(\rho_0 r+\Delta\rho_0),$$

where $$\mu q=L\rho_0 r,$$

neglecting the terms due to cooling. From this equation, neglecting the product of the small quantities, we obtain

$$\mu\,\Delta q=\Delta\rho_0(L-q).$$

The ratio $\frac{\Delta\rho_0}{\mu}$ is the rate of increase of mass of that part concerned above. Hence, if the total weight of the fish-body increases from W to $W+\Delta W$, we can put,

$$\frac{\Delta\bar{q}}{L-\bar{q}}=\frac{\Delta W}{W},$$

taking the mean value of $\frac{\Delta\rho_0}{\mu}$ in the body.

According to S. Ogura and K. Fujikawa, the increment of the weight of

frozen fishes is about 2 %~4 % of the original weight. Hence even when we keep a fish in brine for 24 hours, the order of magnitude of the ratio $\frac{\Delta W}{W}$ may be 0.1 or less. Putting $L=76$, $\bar{q}=51(\theta=8)$, and $\frac{\Delta W}{W}=0.1$, we obtain $\Delta\bar{q}=2.5^{\text{gr. cal}}/_{\text{gr.}}$ Thus we can conclude that the increment of q due to the penetration of water is much less than the decrement due to the penetration of salt.

The penetration of water as well as the freezing of water increase the total volume of fish. According to Plank[1], the amount of increase of volume is about 7~8 % of the original volume. This is given in the form:

$$\frac{\Delta V}{V}=\frac{\rho_0 r(1-\sigma)}{\sigma}+\frac{\Delta W}{W}\frac{\mu}{\sigma},\quad \text{or}\quad \frac{\Delta V}{V}=\frac{\rho_0(1-\sigma)}{\sigma}\left(1-\frac{\theta_0}{\theta}\right)+\frac{\Delta W}{W}\frac{\mu}{\sigma},$$

σ being specific weight of ice. Putting $\theta_0=1.5$, $\theta=8$, $\frac{\rho_0}{\mu}=0.73$, $\mu=1.05$, $\sigma=0.92$ and $\frac{\Delta W}{W}=0.02$, we get $\frac{\Delta V}{V}=7.9\times10^{-2}$.

With respect to the effect of pressure, we can consider that the elasticity of the frozen layer in fish-body can not bear so great a pressure as in the case of frozen ice in a large vessal. On the other hand, the depression of freezing point of water is only 0.82° C even when the pressure increases by 100 kg./cm². Hence the effect of increase of pressure on the value of q in the interior of the body of brozen fish may be negligible. The effect of change of pressure on the increase of volume may also be small, seeing that the compressibility of water is very small, *i. e.* the water changes only 0.52 % of its original volume even when the pressure increases by 100 kg./cm².

5. To study the cases in each of which the temperature, $-\theta_e$, of the medium is different, let the mean temperature of fish-body be $-\theta$ and assume that the heat loss of the body per unit time is proportional to the difference, $\theta_e-\theta$. Let l be the length indicating the linear dimension of the size of fish of a definite sort. Then the volume and the area of the external surface of fish-body are Vl^3 and Sl^2 respectively, where V and S are constants depending upon the sort of fish. The thermal equation of freezing takes the form:

$$Vl^3\frac{dq}{dt}=kSl(\theta_e-\theta),\quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(11)$$

(1) Plank, Ehrenbaum u. Reuter: Die Konservierung von Fischen durch das Gefrierverfahren. 1916.

where k is a certain constant not depending upon l. Putting $q=L\,ar$, and $1-r=\frac{\theta_0}{\theta}$, where $a=\frac{\rho_0}{\mu}$, we have

$$q=La\theta_0\left(\frac{1}{\theta_0}-\frac{1}{\theta}\right),\quad \therefore\quad dq=La\,\frac{\theta_0}{\theta^2}\,d\theta.$$

Hence, (11) becomes

$$La\theta_0\frac{d\theta}{\theta^2(\theta_e-\theta)}=k\frac{S}{Vl^2}\,dt.$$

If $\theta=\theta_0$ at $t=0$, we have

$$\frac{Sk}{Vl^2}\,t=La\,\theta_0\left\{\frac{1}{\theta_e}\left(\frac{1}{\theta_0}-\frac{1}{\theta}\right)-\frac{1}{\theta_e^2}\,ln\,\frac{\frac{1}{\theta}-\frac{1}{\theta_e}}{\frac{1}{\theta_0}-\frac{1}{\theta_e}}\right\},$$

or

$$\frac{Sk}{Vl^2}\,t=\frac{q}{\theta_e}-\frac{La\theta_0}{\theta_e^2}\,ln\,\frac{Q-q}{Q},\quad \ldots\ldots\ldots\ldots\ldots\ldots(12)$$

where Q represents the same quantity as Q in the equation (10).[1]

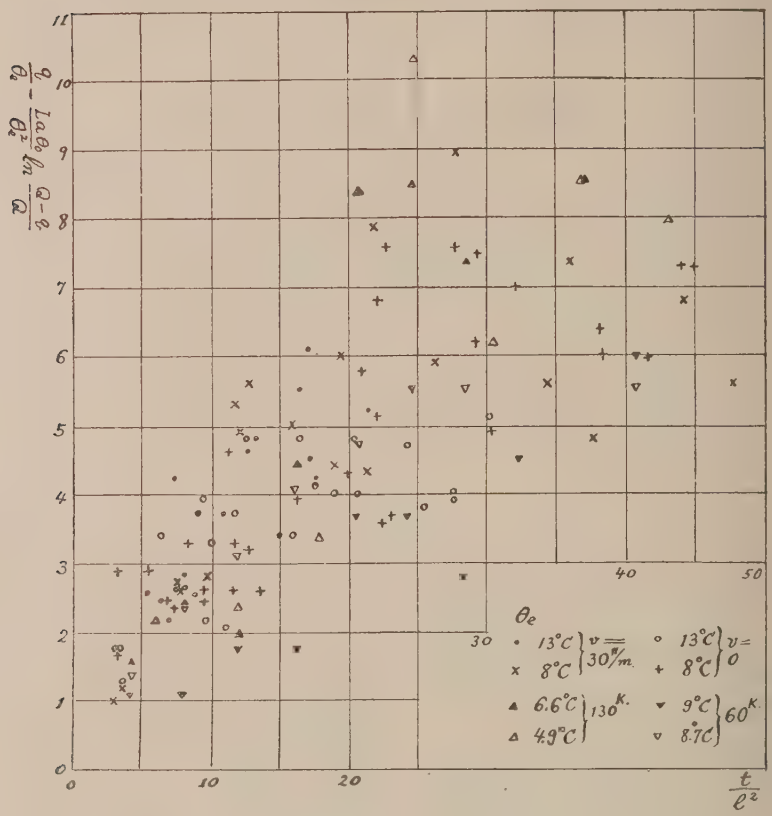
Fig. 9 shows the relation between the quantities, $\frac{q}{\theta_e}-\frac{La\theta_0}{\theta_e^2}\,ln\,\frac{Q-q}{Q}$ and $\frac{t}{l^2}$, calculated from the experimental data obtained by Z. Ogura and K. Fujikawa. In Fig. 9 this relation is approximately represented by the equation (12), which enables us to compare the rates of increasing of the "cold quantity" in the cases of freezing fishes of the same sort in the mediums of different temperatures. The data for the cases of samples which were frozen one by one are given in Tab. I. The other cases are those of freezing a mass of fishes, and the data are given in Tab. III. The temperature of medium, in the cases of the mass of 130 *Kwan* (=490 Kg.), was variable in the experiment of those authors,

(1) Neglecting the higher orders of r and putting $\theta=\theta_0(1+r)=\theta_0\left(1+\frac{q}{La}\right)$, we obtain a similar equation, instead of the relation (12). Namely we get

$$\frac{SK}{Vl^2}\,t=-\frac{La}{\theta_e}\,ln\,\frac{Q-q}{Q},$$

which seems as if to be identical with the empirical equation (10), when we put $\eta=k\,\frac{S}{V}\,\frac{\theta_0}{La}$. But since η, in the equation (10), varies as θ_e varies, and the variation of $k\,\frac{S}{V}\,\frac{\theta_0}{La}$ with θ_e may be too small to explain this fact, the meaning of η may be somewhat other than $\eta=k\,\frac{S}{V}\,\frac{\theta_0}{La}$.

Fig. 9.



+ × ○ ● Samples were frozen one by one at a constant temperature.
△ ▲ A mass of 130 *Kwan* (490 Kg.) of mackerels was frozen at the same time.
▽ ▼ A mass of 60 *Kwan* (230 Kg.) was frozen at a constant temperature.

and the right-hand side of the equation (12) was calculated with the average values of θ_e. In the case of the mass of 60 *Kwan* (=230 Kg.) the temperature of brine was kept constant by adding ice pieces and solid common salt directly into the brine. We cannot find any certain cause to explain the fact that in the case of 60 *Kwan* the value of the quantity on the right-hand side of the equation (12) is less than those in other cases.

From the equation (11), we get

$$\frac{V}{Sk} dq = \frac{\theta_e - \theta}{l^2} dt.$$

Table III.

t: time in minutes; q: "cold quantity" (in gr. cal./gr.);
$-\theta_e$: temperature of medium (brine).

a. Mackerels: 130 *Kwan* (1)

t	θ_e	q
0	12.5~12.4	——
20	——	9.2
30	8.0 ~ 7.5	——
40	——	13.9
60	6.5 ~ 5.5	11.2
80	——	22.6
90	6.6 ~ 5.7	——
100	——	37.1
120	6.5 ~ 5.4	37.4
140	——	34.0
150	6.5 ~ 6.3	——
160	——	48.0
180	7.0 ~ 6.3	37.5
210	7.3 ~ 6.4	——
4 ×60	7.7 ~ 6.8	36.8
4.5×60	7.9 ~ 7.1	——
5 ×60	8.0 ~ 7.4	51.2
5.5×60	8.4 ~ 8.2	——
6 ×60	8.6 ~ 8.2	53.7
6.5×60	8.9 ~ 8.5	——
7 ×60	8.9 ~ 8.5	54.2
7.5×60	9.9 ~ 9.1	——
8. ×60	10.4~ 9.6	52.7
9. ×60	——	49.5
9.5×60	11.0~10.7	55.5
10 ×60	11.8~11.4	
10.5×60	12.5~12.1	

b. Mackerels: 130 *Kwan* (2)

t	θ_e	q
0	12.1~12.0	——
0.5×60	——	8.6
1 ×60	6.5 ~ 6.1	9.0
1.5×60	4.5 ~ 4.2	12.1
2 ×60	4.5 ~ 4.1	30.2
2.5×60	4.8 ~ 4.3	20.2
3 ×60	5.1 ~ 4.6	46.4
3.5×60	5.3 ~ 4.6	25.1
4 ×60	5.5 ~ 5.0	44.0
4.5×60	5.9 ~ 5.3	49.7
5 ×60	6.1 ~ 5.4	52.7
5.5×60	6.5 ~ 6.0	
6 ×60	7.1 ~ 6.6	

c. Mackerels: 60 *Kwan* (1)

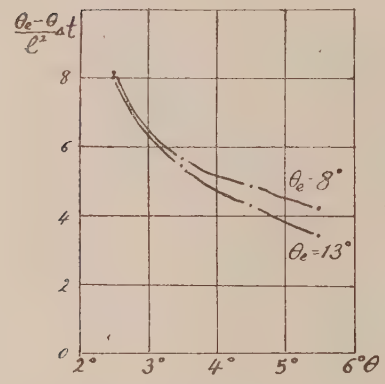
t	θ_e	q
20	7.0	12.4
40	7.0	20.5
60	8.0	25.7
80	8.0	31.4
100	9.0	36.7
120	9.0	42.0
140	9.0	42.0
160	9.5	53.6
180	——	——
200	10.0	42.0
220	10.0	53.6
240	10.0	53.6

d. Mackerels: 60 *Kwan* (2)

t	θ_e	q
20	9	10.2
40	9	10.2
60	9	15.5
80	9	15.5
100	9	31.4
120	9	31.4
140	9	23.5
160	9	36.7
180	9	53.6
200	9	47.3
220	9	53.6
240	9	53.6

This equation expresses that the rate of increasing of q is proportional to $\frac{\theta_e-\theta}{l^2}$. Fig. 10 shows the relation between $\frac{\theta_e-\theta}{l^2}\Delta t$ and θ, calculated from the data given in Fig. 2. Δt is time-interval in which the temperature of fish-body changed from $-\theta$ to $-(\theta+1°\,C)$. In Fig. 10 the value of $\frac{\theta_e-\theta}{l^2}\Delta t$ is almost independent of the temperature of the brine θ_e. That the rate of increasing of q is proportional to $\frac{\theta_e-\theta}{l^2}$ is verified.

Fig. 10.



If in Δt, a definite change of temperature of fish-body, *e. g.* $\Delta\theta=1°$C, takes place, $\frac{\theta_e-\theta}{l^2}\Delta t$ is independent of (l and) the temperature of medium, θ_e.

In concluding this paper, the writer's sincerest thanks are due to Dr. Morisaburô Tauti for the kindness in giving him valuable advices and for the constant guidance throughout the course of this investigation.

Summary.

In the following conclusions, fishes under consideration are supposed to be kept at 0° C before they are put in the brine.

1. In the case of freezing a fish, let q be the quantity of heat taken away from a unit mass of fish-body. When fishes of the same sort are frozen in the brine of which the temperature is kept constant, the time, t, taken to increase the value of q to a definite amount is proportional to the square of the length, l, of a corresponding part of fish-bodies, (Fig. 1), *i. e.*

$$t \propto l^2, \qquad \text{or} \quad q=fn\left(\frac{t}{l^2}\right).$$

2. In the course of freezing, the thickness, d, of the layer of muscles in which the frozen state is recognizable, increases uniformly with time, t. For fishes of the same sort, we have the following relation (Fig. 4):

$$\frac{d}{l} \propto \frac{t}{l^2}$$

3. The distribution of temperature in a fish-body varies with time as shown in Fig. 5.

4. The change of pressure within fish-muscle, the penetration of water as well

as the penetration of salt into fish-body change the value of q. But the effect of the penetration of salt is the most important.

5. When we freez fishes of the same sort in various mediums, of which the temperatures, θ_e, are different one from another:—

i) We have a general relation between time of freezing, t, and the mean value of q:

$$\frac{\bar{q}}{\theta_e} - \frac{La\theta_0}{\theta_e^2} ln \frac{Q-\bar{q}}{Q} \infty - \frac{t}{l^2},$$

in which L is the heat of freezing of water (at an average temperature); a, the percentage of water contained in fish-muscle; θ_0 the freezing point of fish-muscle, and Q, the value of q, when the temperature of fish-body becomes equal to that of the surrounding medium.

ii) The time-interval, Δt, in which the temperature of fish-body varies from a definite value θ, by 1° C, satisfies the relation:

$$\frac{\theta_e-\theta}{l^2} \Delta t = fn(\theta),$$

where the function on the right-hand side is independept of θ_e and l.

March 12, 1928.

Physical Laboratory,
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ON THE ACTION OF ELECTRIC CURRENT ON FISHES I.

EXCITATION AND NARCOSIS.

By

Mituyo Okada.

With regard to the action of electric current on fishes, Ferdinand Scheminzky[1] ound that when the intensity of current, either direct or alternating, gradually increases, four successive steps of action take place. When the intensity of current is sufficiently low there is no action on fishes but when it increases to a certain value a kind of action is observed. This action is "erste Erregung," as called by F. Scheminzky. At a certain intensity higher than that value the second action, "electrotaxis," as called by him, occurs and the fishes assume a definite orientation in relation to the direction of stream line of the current. The third action is "electronarcosis," as called by him—by the term which was first used by Blasius and Schweizer[2]—and fishes are benumbed. Finally they are instantaneously killed by the electric shock. It was also found out that the sensitivity of fishes differs according to their size; the smaller the fishes, the less their sensitivity. He says that the action of the current is determined by the current density.

In the present paper, the results of experiments which were attempted to analyse the influences corresponding to Scheminzky's "erste" and the last (causing death) action are mentioned.

The apparatus used in the experiments consisted of four rectangular wooden aquariums, each furnished with one set of vertically supported electrodes as shown in Tab. I, and was supplied with alternating current of 50 cycles, of which the voltage was controlled with a multivolter and resistances.

In a preliminary experiments, it was known that the distribution of current in these aquariums was two-dimensional, and the effect of polarization at the surface of electrodes was negligible. Consequently, the potential at any point in water depends only on the voltage supplied on the electrodes and is proportional to it.

1) Ferdinand Scheminzky: Der Fischfang mit Elektrischem Strom. Nachrichtenblatt f. Fischzucht u. Fischerei. 1. S. 49 (1927); Versuche über Elektronarkose. Pflüger's Arch. f. d. ges. Physiol. Bd. 202, S. 200~216 (1924).

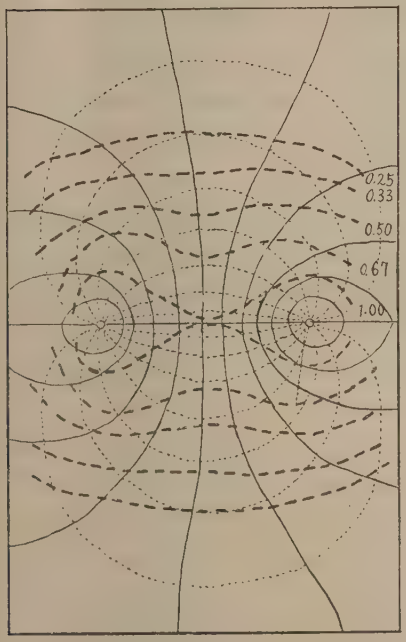
2) Blasius u. Schweizer: Elektrotropismus und verwandte Erscheinungen. Pflüger's Arch. f. d. ges. Physiol. Bd. 53, S. 493~543, (1893).

Table. I.

Aquariums			Electrodes		
Name	Breadth	Height	Kind	Size	Position
A	1.8m×1.2m	0.3m	Rods of lead	diam. 1.2cm	On the centre line parallel to the shorter sides of aquarium each appart 30cm from both longer sides.
B	1.8 ×1.2	0.3	,,	,,	
C	2.00×0.22	0.1	Plates of zinc-covered iron	22cm×8cm	At the both ends of the aquarium.
D	3.00×0.25	0.1	,,	25cm×18cm	

In order to know the distribution of current in each apparatus shown in Tab. I, the equipotential lines, the stream lines and the lines of a constant potential-drop—the lines each of which shows a locus of points having potential-drop of a constant value per unit length along the stream lines—were determined in the following manner.

Fig. 1.



Distribution of current in A-aquarium, ——: equipotential lines; ....: stream lines; — — —: lines of constant potential-drop.

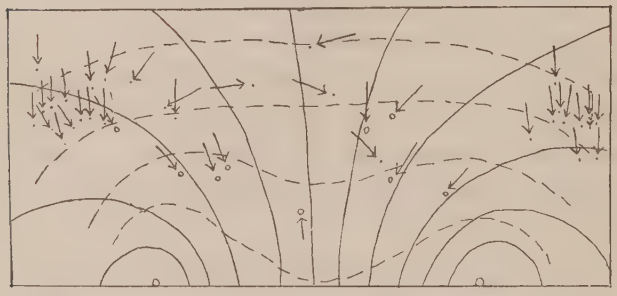
The forms of the equipotential lines were determined by alternating current employing needles connected to a telephone. Next, by direct current the relation between each of potentials at several points in the field and the supplied voltage was determined using needles connected to a pointergalvanometer or a potentio-voltmeter. The stream lines and the lines of constant potential-drop were graphically obtained. In the aquariums A and B the distribution of current was as shown in Fig. 1. In the aquariums C and D, all the equipotential lines were parallel one to another and were perpendicular to the longer sides of the aquarium. The potential-drop per 1cm along the stream line was, in C, $4.35\times10^{-3}\ V$, and in D, $2.71\times10^{-3}\ V$, where V is the voltage between the electrodes.

The following two methods of experiments were employed :—

i) In A or B aquarium. One or many

fishes were put in the aquarium and the current of moderate intensity was supplied at the instant when the fishes were so far distant from the electrodes, that the suppleid current had no effect on them. When a fish approached to the electrodes within a definite limit, it suddenly felt the current taking a rapid motion, or was benumbed and dead ceasing to breathe. At that instant, when the fish felt the shock or died beaten by it, the position and orientation of the fish-body were recorded, for example, as shown in Fig. 2. Comparing Fig. 2 with Fig. 1, the potential-drop per unit length at that position and along the median line of the fish-body was calculated.[1]

Fig. 2.



Position where a goldfish felt the current. Orientation is indicated by arrows.
l=12.0 cm ; V=15 volt ; $\kappa=6.0\times10^{-5}\sim6.7\times10^{-5}$ cm ohm^{-1} ;
d=15 cm ; θ=11.8°~13.1° C.

ii) In C or D aquarium. A fish was put in the aquarium ; the current was supplied and its intensity was gradually increased; and then the minimum voltage was obtained to make fish feel the electric shock or dead beaten by it. From this minimum voltage, the potential-drop per unit length was calculated.

From Fig. 2 it is evident that the fishes approach nearer to the electrodes when they are swimming along an equipotential line than along a stream line. Hence in the following data only those cases, where the fish was swimming along or nearly along a stream line, were taken into account. In C or D aquarium the voltage was recorded only when the fish assumed the orientation parallel or nearly parallel to the stream lines.

Three series of experiments were done. In the first series, the relation between the size of fish-body and the potential-drop mentioned above was studied in the second series, the relation between the electric conductivity of the mediu and the potential-drop ; and in the third series, the relation between th potential-drop and the voltage on the electrodes in A or B aquarium. Tl results are given in Tabs. II, III and V.

Following notations are used.

1) In these calculations, the disturbance of the field due to the existence of fish-body was not taken into account.

第 二 表 Table II.

魚種 Kind of Fishes	作用 Action	水槽 Aquarium	l	v_0	$\frac{v_0}{l}$	d	θ	κ
きんぎょ	感電	A(V=15)	1.0	0.6×10^{-1}	6.0×10^{-2}	15	18.5	—
			3.4	0.98	2.9	13	14~15	7.2×10^{-5}
goldfish	First		4.6	1.44	3.1	14	16.9	8.0
	Excita-		4.7	1.30	2.8	13	15.0	6.8
* 球金	tion		4.9*	1.56	3.2	13~15	13.0~14.9	6.3~6.8
			4.9*	1.49	3.0	13~15	11.8~14.7	6.3~6.7
			5.0	1.83	3.7	15	11.8	6.3
			5.0	1.39	2.8	13~15	13.0~14.5	6.4~6.6
			5.0	1.37	2.7	13~15	13.0~13.2	6.2~6.4
			5.4	1.33	2.5	13~15	13.0~13.7	6.3~6.4
			5.5*	2.12	3.9	10~13	13.0~14.8	6.8~7.2
			6.0	1.79	3.0	13	12.5	6.5~7.0
			6.4	1.89	3.0	10~13	13.5~15.1	6.8
			6.5	1.88	2.9	14	17.5	7.6~9.5
			6.7	1.84	2.8	11~13	12.8~14.5	6.4~6.7
			7.9	2.20	2.8	10~13	13.5~14.2	6.9~7.2
			7.9	2.27	2.9	14	15.6~17.8	7.6~9.0
			8.0	2.77	3.5	13	15.9	6.9
			10.2	2.70	2.7	14	15.5	9.0
			12.0*	3.55	3.0	15~16	11.8~13.1	6.3~9.7
まふぐ	感電	C	8.9	2.53×10^{-1}	2.8×10^{-2}	4.0	19.5	2.09×10^{-2}
			9.0	2.40	2.7	〃	〃	〃
Spheroides sp.	First		9.5	2.74	2.9	〃	〃	〃
	Excita-		10.8	3.05	2.9	〃	〃	〃
	tion		11.3	3.16	2.8	〃	〃	〃
			10.7*	2.12	2.0	〃	〃	〃
* 膨レタルモノ			10.7*	2.24	2.1	〃	〃	〃
			11.2*	2.43	2.2	〃	〃	〃
			11.3*	2.33	2.1	〃	〃	〃
			11.5*	2.06	1.8	〃	〃	〃
			11.7*	2.20	1.9	〃	〃	〃
			12.2*	2.66	2.2	〃	〃	〃
			12.6*	3.05	2.4	〃	〃	〃
こひ	感電	C	0.60	2.62×10^{-1}	4.4×10^{-1}	6.3	21.°3	9.64×10^{-4}
		(* B)	0.60	2.76	4.6	〃	〃	〃
Cyprinus Carpio L.	First		0.65	3.16	4.9	〃	〃	〃
	Excita-		0.70	2.60	3.7	〃	〃	〃
	tion		0.70	3.24	4.6	〃	〃	〃
			0.70	3.53	5.0	〃	〃	〃
			0.75	3.45	4.6	〃	〃	〃
			4·1	1.13	1.8×10^{-2}	7.4	22.°5	7.45×10^{-4}
			4.3	1.04	2.4	〃	〃	〃
			4.6	2.24	4.9	〃	〃	〃
			6.2	1.27	2.1	〃	〃	〃
			7.0	1.90	2.7	〃	〃	〃
			7.1	1.43	2.0	〃	〃	〃
			7.1	2.09	3.0	〃	〃	〃
			7.1	1.61	2.3	〃	〃	〃
			7 *	0.90	1.3	7.7	18.°5	6.74×10^{-4}
			7 *	1.10	1.6	〃	〃	〃
			9 *	1.25	1.4	〃	〃	〃
			11. *	1.65	1.5	〃	〃	〃
ふな	感電	C	0.95	1.29×10^{-1}	1.36×10^{-1}	7.4	22.°5	7.45×10^{-4}
			0.95	1.33	1.40			
Carassius Auratus L.	First		1.0	1.44	1.44			
	Excita-		1.05	1.57	1.49			
	tion		1.1	1.58	1.44			
			1.1	1.68	1.53			
			1.3	1.94	1.49			
			1.55	1.27	8.22×10^{-2}			
			1.70	1.20	7.04			
			4.2	2.94	7.00			
			5.2	1.91	3.68			
			5.4	1.52	2.82			
			5.9	2.01	3.41			
			6.0	1.52	2.54			
			6.9	2.72	3.94			

魚種 Kind of Fishes	作用 Action	水槽 Aquarium	l	v_0	$\frac{v_0}{l}$
こひ	麻痺	*C*	0.70	0.76	10.8×10^{-1}
			0.75	0.65	8.7
Cyprinus carpio L.	Narcosis		4·0	1.37	2.4
		$d=6.2$	4.3	0.89	2.1
		$\theta=22.°4$	4.7	1.27	2·7
		$\kappa=1.36\times10^{-3}$	5.0	1.25	2.5
			6.2	1.46	2.4
			6.5	1.82	2.8
			6.6	1.85	2.8
			7.1	1.55	2.2
			7.1	1.65	2.3
			7.2	1.70	2.4
			7.5	1.64	2.2
			7.5	1.81	2.4
			8.2	1.86	2.3
			8.2	1.87	2.3
			8.7	2.21	2.5
			8.9	1.87	2.1
			9.0	2.20	2.5
			9.5	2.36	2.5
			9.5	1.82	1.9
			9.5	1.96	2.1
			9.5	2.29	2.4
			9.6	2.22	2.3
			9.6	2.52	2.6
			9.7	2.63	2.7
			9.8	1.97	2.0
			10.0	2.36	2.4
			10·0	2.27	2.3
			10.3	2.56	2.5
			10.5	2.11	2.0
			10.7	2.15	2.0
			10.7	2.15	2.0
			10·7	2.48	2.3
			10.9	2.05	1.9 2.36
			11.2	1.32	1.2
			16.1	1.96	1.2 1.2
ふな	麻痺	*C*	0.9	0.78	8.67×10^{-1}
			1.0	0.93	9.3
Carassius Auratus L.	Narcosis	$d=6.2$	1.2	1.17	9.7
		$\theta=22.°4$	1.2	0.95	7.9
		$\kappa=1.36\times10^{-3}$	1.2	0.93	7.8
			1.4	1.21	8.7
			1.5	1.31	8.7
			1.6	1.34	8.4
			1.65	1.35	8.2
			1.7	1.46	8.7
			1.95	1.60	8.2
			2.4	1.67	7.0
			2.6	1.18	4.6
			2.7	1.14	4.8
			4.2	1.08	2.58
			4.4	0.81	1.84
			4.4	0.64	1.46
			4.5	0.85	1.88
			4.6	1.03	2.23
			5.6	1.40	2.49
			5.6	1.08	1.93
			5.7	1.07	1.88
			6.5	1.34	2.06
			6.6	1.36	2.06
			7.2	1.70	2.36
			7.3	1.69	2.32
			8.3	1.85	2.23
			10.4	1.91	1.84
			11.8	1.76	1.49
			16.1	1.68	1.04
はぜ	麻痺	*D*	2.8	1.45	5.18×10^{-1}
			2.9	1.29	4.47
Acanthogobius sp.	Narcosis	$d=4.3$	3.2	1.19	3.72
		$\theta=22.°0$	3.6	1.27	3.53
		$\kappa=2.2\times10^{-4}$	3.9	1.31	3.36
			4.7	1.26	2.68
			5.2	1·33	2.25
			5.7	1.53	2.68

第　三　表　Table III.

きんぎょ 感電 A 水槽 Goldfish First Excitation, Aquarium A. ($V=15$)

l	v_0	$\frac{v_0}{l}$	d	θ	κ
4.9	0.149	0.0304	13～15	11·8～14.7	$6.3\sim6.7\times10^{-5}$
4.9	0.156	0.0318	13～15	13.0～14.9	6.3～6.8
5.0	0.183	0.0366	15	11.8	6.3
5.5	0.212	0.0385	10～13	13.4～14.8	$6·8\sim7.2\times10^{-5}$
6·7	0.184	0.0275	11～13	12.8～14.5	6.4～6.7
8.0	0.277	0.0346	13	15.9	6.9
	0.194	0.0332			6.6×10^{-5}
4.9	0.127	0.0259	11.3	14.1	2.6×10^{-4}
5.0	0.200	0.0266	11.3	14.8	2.7
5.5	0.155	0.0282	11.3	13.5	2.6
6.7	0.158	0.0236	11.3	14.9	2.7
8.0	0.200	0.0250	11.3	13.7	2.6
	0.168	0.0259			2.6×10^{-4}
4.9	0.109	0.0222	10.0	14.5	6.1×10^{-4}
5.0	0.120	0.0240	10·0	14.5	6.1
5.5	0.137	0.0249	10.0	14.2	6.1
6.7	0.128	0.0191	10.0	14.5	6.1
8.0	0.151	0.0189	10.0	14.3	6.1
	0.129	0.0218			6.1×10^{-4}
4.9	0.107	0.0218	8.8	16.5	$3·1\times10^{-3}$
4.9	0.088	0.0180	8.7	16·2	3.1
5.0	0.121	0.0242	8.8	15.8	3.2
6.7	0.115	0.0172	8.8	16.5	3.2
8.0	0.148	0.0185	8.8	15.3	3.1
	0.916	0.0199			3.1×10^{-3}

まふぐ 感電 C 水槽 *Spheroides sp.* First Excitation, Aquarium C.

l	$\frac{v_0}{l}$					
1.2	0.0617	0.0423	0.0309	0.0260	0.0247	0.0176
1.3	0.0794	0.0538	0.0335	0.0275	0·0264	0.0273
1.6	0.0688	0.0537	0.0406	0.0300	0.0247	0.0242
1.8	—	0.0468	0.0419	0.0397	0.0397	0.0291
2.0	0.0684	0.0516	0.0326	0.0285	0.0304	0.0251
2.5	0.0600	0.0468	0.0357	0.0282	0.0220	0.0269
	0.0677	0.0412	0.0359	0.0300	0.0280	0.0250
d	4.4	—	4.5	4.7	4.4	4.3
θ	19.6	19.6	19.6	19.6	19.6	19.6
κ	3.12×10^{-2}	7.20×10^{-4}	2.02×10^{-3}	6.05×10^{-3}	1.89×10^{-2}	3.97×10^{-2}

こひ 感電 B 水槽 *Cyprinus Carpio L.* First Excitation, Aquarium B.

l	$\frac{v_0}{l}$				
7	0.0170	0.0170	0.0165	0.0130	0.0135
7	0.0225	0.0170	0.0170	0.0155	0.0165
9	0.0160	0·0160	0.0165	0.0140	0.0150
11	0.0180	0.0170	0.0150	0.0150	0.0130
	0.0185	0.0168	0.0160	0.0145	0.0145
d	7.7	7.7	7.6	7.7	7.7
θ	19.5	18·5	18.5	19.5	18.5
κ	2.23×10^{-4}	2.86×10^{-4}	4.68×10^{-4}	6.74×10^{-4}	1.74×10^{-3}

いな 感電 D 水槽 *Mugil cephalus L.* First Excitation, Aquarium D.

l	$\frac{v_0}{l}$				
3.0～3.7	0.0434	0.0466	0.0285	0.0263	0.0225
	0.0475	0.0399	0.0254	0.0244	0.0222
	0.0393	0.0401	0.0263	0.0286	0.0217
	0.0364	0.0320	0.0238	0.0252	0.0230
	0.0410	0.0227	0.0285	0.0222	0.0198
	0.0382	0.0293	0.0254	0.0241	0.0233
	0.0361	0.0280	0.0263	0.0192	0.0217
	0.0350	0.0268	0.0309	0.0238	0.0209
	0.0396	0.0332	0.0269	0.0243	0.0129
d	4.1	4.1	4.2	4.2	3.6
θ	—	20.8	20.7	21.7	2.18
κ	9.30×10^{-4}	1.31×10^{-3}	4.89×10^{-3}	9.70×10^{-3}	4.30×10^{-2}

まふぐ 麻痺 C 水槽 *Spheroides sp.* Narcosis, Aquarium C.

l	$\frac{v_0}{l}$	l	$\frac{v_0}{l}$	l	$\frac{v_0}{l}$	l	$\frac{v_0}{l}$
9.0	0.272	9·3	0.22	8.8	0.175	9.4	0.23
10.5	0.237	11.5	0·23	10.3	0.180	10.7	0.19
10.6	0.230	11.4	0.18	10.9	0.155	11.6	0.24
	0.250		0.21	11.9	0.165		0.22
					0.169		
d	5.7		5.9		4.2		5.4
θ	19.0		19.0		18.8		19.4
κ	1.77×10^{-3}		6.91×10^{-3}		2.37×10^{-2}		2.99×10^{-2}

いな 麻痺 C 水槽 *Mugil cephalus,* Narcosis, Aquarium C.

l	$\frac{v_0}{l}$					
2.8～3.9	0.531	0.423	0.382	0.271	0.260	0.206
	0.550	0.412	0.385	0 278	0.298	0.222
	0.545	0.410	0.374	0.260	0.266	0.238
	0.580	0.436	0.350	0.255	0.271	0.241
	0.555	0.410	0.382	0.278	0.252	0 233
	0.552	0.418	0.385	0.268	0.254	0.233
			0.376		0.267	0.233
						0.229
d	4.2	4.5	4.2	4.1	4.2	3.3
θ	23.6	20.4	24.6	24.6	23.0	22.0
κ	8.42×10^{-5}	3.29×10^{-4}	1.24×10^{-3}	4.19×10^{-3}	1.25×10^{-2}	4.68×10^{-2}

はぜ 麻痺 D 水槽 *Acanthogobius sp.* Aquarium D.

l	$\frac{v_0}{l}$				
3.1～5.7	0.268	0.190	0.195	0.179	0.193
	0.255	0.222	0.173	0.198	0.193
	0.268	0.217	0.222	0.238	0 190
	0.353	0.206	0.242	0.205	0.192
	0.372	0.219	0.277		
	0.336		0.222		
	0.219				
d	4.3	4.4	4.5	4.2	3 8
θ	22.4	21.7	22.4	24.2	23.4
κ	1.55×10^{-4}	6.73×10^{-4}	1.55×10^{-3}	7.95×10^{-3}	4.63×10^{-2}

l : length of fish-body (in cm) ; v_0 : potential drop per l cms along the median line of fish-body ; V : voltage between the electrodes (in volts) ; d : depth of medium (in cm) ; θ : temperature of medium ; κ : conductivity of medium (cm ohm^{-1}).

Experiment I. Variation of sensitivity according to the length of fish-body.

The results obtained in the first series of experiments are shown in Tab. II and Fig. 3.

In the case of goldfish the relation between v_0 and l seems to be graphically represented by a straight line passing through the origin, while in the case of *Carassius auratus* (*Linné*) in wild stock, or *Acanthogobius sp.*, v_0 seems to be almost constant. If we put

$$v_0 = al,$$

and assume that a is a constant depending upon some factors, which determine the average size of body, *e. g.* the different stage of life, and depending on the kind of fish, on the conductivity of the medium, etc., then the relation is explainable in both cases above-mentioned, *i. e.* in the cases of goldfish and *Carassius auratus* (*Linné*), as well as in all other cases, especially of *Cyprinus carpio Linné*.

Experiment. II. Variation of sensitivity according to the conductivity of medium.

The results in the second series of experiments are given in Tab. III. and Fig. 4. In the experiments of this series, the medium of different conductivity was obtained by mixing fresh water and sea-water in various ratios.

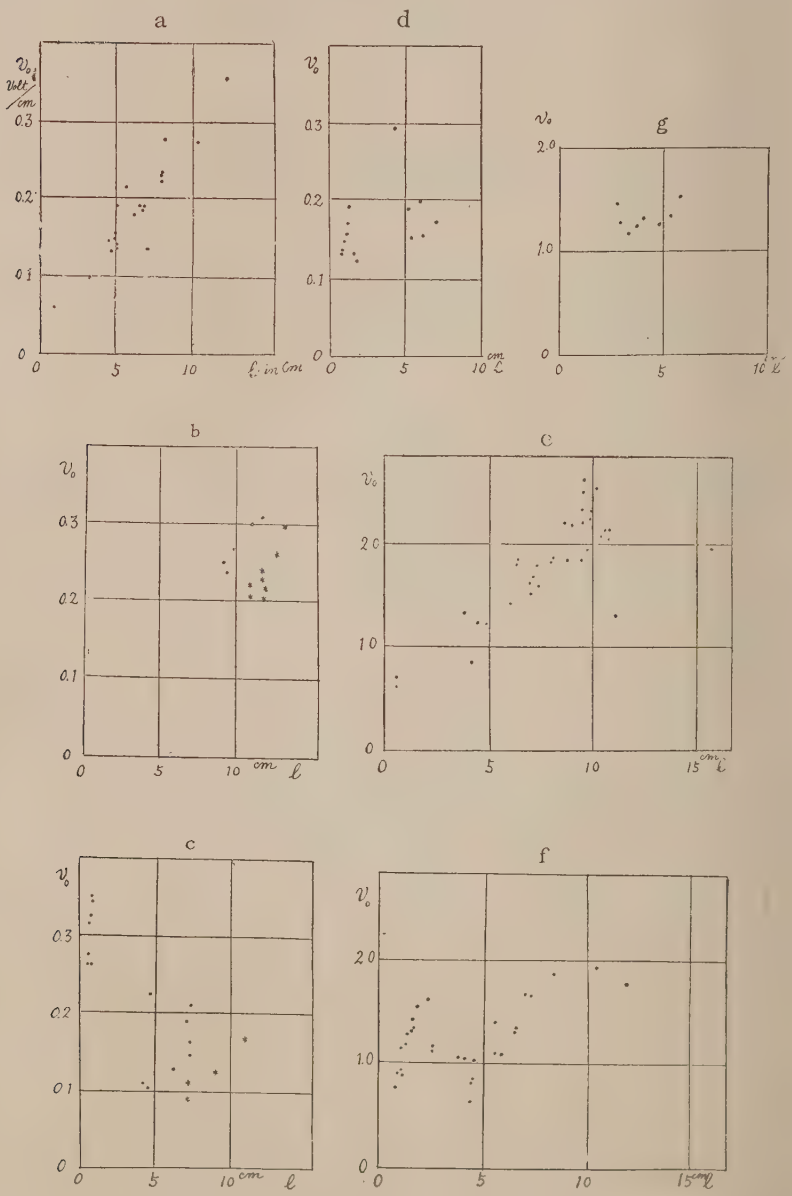
The relation between $\frac{v_0}{l}\kappa$ and κ is given in Tab. VI and Fig. 5.

$\frac{v_0}{l}\kappa$ represents the current-density. It is never constant as shown in Fig. 5. The variation of $\frac{v_0}{l}$ is rather small as compared with that of $\frac{v_0}{l}\kappa$ as shown in Fig. 4, (b). In every case it seems as if $\frac{v_0}{l}$ has an asymptotic value, and if we put

$$\left(\frac{v_0}{l} - b\right)\kappa = C, \text{ where } b, \text{ and } C \text{ are constants,}$$

we obtain the relation represented by a thick line in Fig. 4 (a). With a few exceptions, the relation between $\frac{v_0}{l}$ and $\frac{1}{\kappa}$, (which is given in Fig. 6), are linear and consequently, the relation between $\frac{v_0}{l}$ and κ is given by the above expression. Generally, however, the relation is more complex.

Fig. 3.

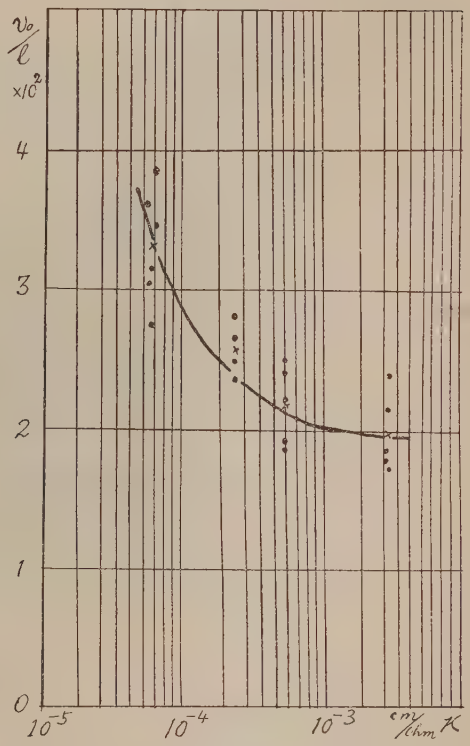


First excitation:—a: goldfish V=15, aq. A; b: *Spheroides sp.* aq. C; c: *Cyprinus carpio L.* aq. C (*B); d: *Carassius auratus L.* aq. C.
Narcosis:—e: *Cyprinus carpio L.* aq. C; f: *Carassius auratus (Linné)*, aq. C; g: *Acanthogobius sp.* aq. D.

Table. IV.

Fishes & Action	$\frac{v_0}{l}$	κ
Goldfish First excitation	2.2×10^{-6}	6.6×10^{-5}
	6.7×10^{-6}	2.6×10^{-4}
	1.31×10^{-5}	6.1×10^{-4}
	6.2×10^{-5}	3.1×10^{-3}
Spheroides sp. First excitation	2.1×10^{-5}	3.12×10^{-4}
	3.0×10^{-5}	7.20×10^{-4}
	7.8×10^{-5}	2.02×10^{-3}
	9.9×10^{-5}	3.97×10^{-3}
	1.8×10^{-4}	6.05×10^{-3}
	5.3×10^{-4}	1.89×10^{-2}
Cyprinus Carpio L. First excitation	4.1×10^{-6}	2.23×10^{-4}
	4.8×10^{-6}	2.86×10^{-4}
	7.5×10^{-6}	4.68×10^{-4}
	9.8×10^{-6}	6.74×10^{-4}
	2.5×10^{-5}	1.74×10^{-3}
Mugil cephalus L. Narcosis	3.7×10^{-5}	9.3×10^{-4}
	4.3×10^{-5}	1.31×10^{-3}
	1.31×10^{-4}	4.89×10^{-3}
	2.33×10^{-4}	9.7×10^{-3}
	9.4×10^{-4}	4.3×10^{-2}
Spheroides sp. Narcosis	6.7×10^{-3}	2.99×10^{-2}
	4.0×10^{-3}	2.37×10^{-2}
	1.45×10^{-3}	6.91×10^{-3}
	4.4×10^{-4}	1.77×10^{-3}
Cyprinus Nar.	3.2×10^{-4}	1.36×10^{-3}
Muzil Cephalus L. Narcosis	4.65×10^{-5}	8.42×10^{-5}
	1.33×10^{-4}	3.29×10^{-4}
	4.66×10^{-4}	1.24×10^{-3}
	1.12×10^{-3}	4.19×10^{-3}
	3.34×10^{-3}	1.25×10^{-2}
	1.07×10^{-2}	4.68×10^{-2}
Acanthogobius sp. Narcosis	7.8×10^{-5}	2.22×10^{-4}
	1.47×10^{-4}	6.73×10^{-4}
	3.28×10^{-4}	1.55×10^{-3}
	8.30×10^{-4}	3.20×10^{-3}
	1.03×10^{-3}	7.95×10^{-3}
	8.90×10^{-3}	4.63×10^{-2}

Fig. 4. a.



Goldfish, First excitation, aq. A (V=15)

Fig. 4. b.

- • Goldfish.
- × *Cyprinus carpio L.*
- ◦ *Acanthogobius sp.*
- ▲△ *Carassius auratus L.*
- ▼▽ *Mugil Cephalus L.*

Upper: Narcosis.
Bottom: First excitation.

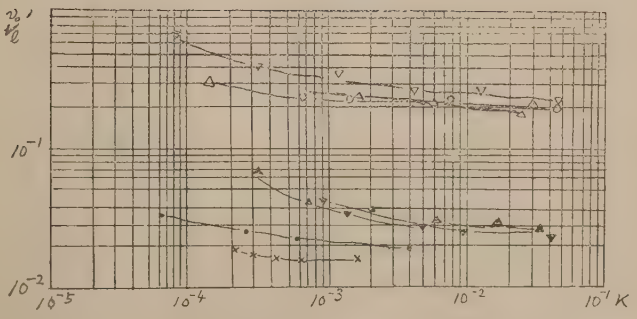


Fig. 5.

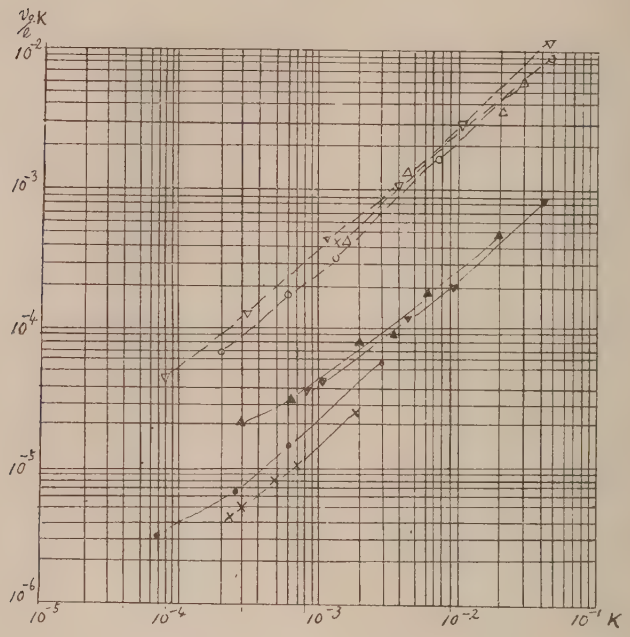
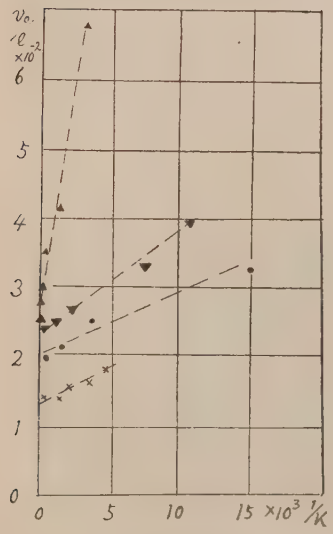
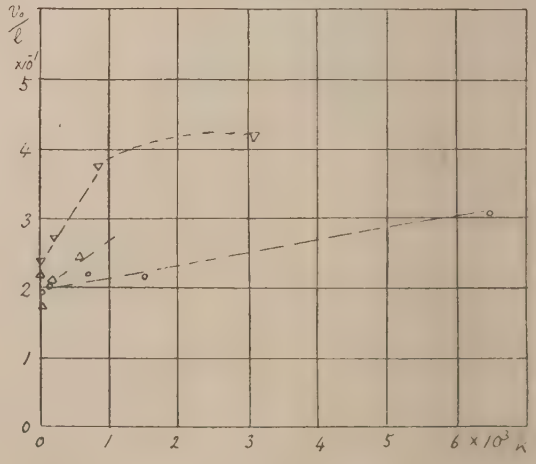


Fig. 6.

a : First excitation ;



b : Narcosis ;



• : Goldfish ; × : *Cyprinus carpio L.*; ▲△ : *Spheroides sp.*;
▽▼ : *Muzil cephalus L.*; ○ : *Acanthogobius sp.*

Experiment III. Sensitivity and the voltage on the electrodes.

The results of the third series of experiments are given in Tab. V, and Fig. 7.

Table. V.

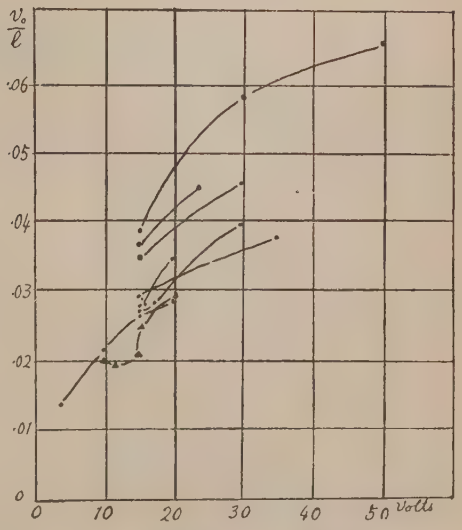
a. Goldfish, First excitation, aquarium A.

l	V	$\frac{v_0}{l}$	d	θ	κ	$\frac{d^2v}{ds^2}$
5.5	15	.0386	10～13	13.5～15.1	6.8×10^{-5}	18
	30	.0578	15.3～12	12.2～15.5	6.3～7.3	12
	50	.0655	11	13.8	7.5	8
7.9	15	.0278	10～13	13.5～14.2	6.9～7.2	11.4
	20	.0342	15	12	6.3	9.6
6.7	15	.0275	11～13	12.8～1.45	6.4～6.7	13.8
	17.5	.0281	15	13	6.6	12.6
	30	.0397	16	12.3	6.7	7.2
3.4	15	.0288	13	14 ～15	7.2	15.0
	35	.0374	16	12.5	6.7	7.0
5.0	15	.0366	15	11.8	6.3	16.2
	24	.0450	15	12.0	6.6	13.5
8.0	15	.0346	13	15.9	6.9	13.6
	30	.0457	10	14.4	6.7	8.4
10.2	4	.0137	14	17.0	7.5	—
	10	.0216	14	17.0	7.5	10.8
	15	.0265	14	15.5	9.0	8.4
	20	.0284	14	17.5	7.6	6.4

b. Spheroides sp. First excitation, aq. B.

l	V	$\frac{v_0}{l}$	d	θ	κ
9～12.	10	.020	4.6	18.0	3.5×10^{-2}
	11.8	.019	4.7	18.0	3.5
	14.8	.021	8.6	19.0	2.5
	15.2	.025	4.7	18.0	3.5
	20.5	.029	4.7	18.0	3.5

Fig. 7.



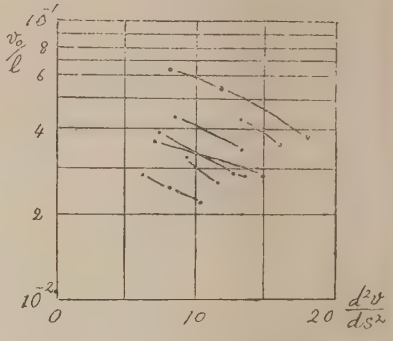
First excitation: —•: Goldfish;
▲: *Spheroides sp.*

$\frac{v_0}{l}$ increases with the voltage on the electrodes. Hence, from this point of view, we can also say that the action of electric currents on fishes is too complex to be attributed to the current density or to the potential-drop. The values of the second derivatives, $\frac{d^2v}{ds^2}$, of the potential along the stream line are graphically calculated and are shown in Tab. V. $\frac{v_0}{l}$ increases when $\frac{d^2v}{ds^2}$ decreases, as shown in Fig. 8.

Concluding from the results obtained, we can say that the action of electric

current on fishes are chiefly due to the potential-drop along the fish-body, and also depends on current-density in the medium, as well as on the rate of increase of the potential-drop along the fish-body, etc.

Fig. 8.



Before closing this paper, the writer's sincerest thanks are due to Dr. Morisaburô Tauti for his earnest guidance throughout the investigation. The writer wishes to express his warmest thanks to Mr. Nobutaka Nakai, Mr. K. Matui and other members of Toyohasi Piscicultural Experiment Station, for their valuable advices, and also to Mr. K. Miyosi and Mr. K. Tamura for their assistances.

July, 1923

Physical Laboratory,
Imp. Fish. Imstitute. Tôkyô.

ON THE MOVEMENT OF A FISH-GROUP. I.

ON THE DIRECTION OF A FISH-GROUP ON PASSING THE END OF A WALL ALONG WHICH IT HAS MOVED.

By

Dr. M. Tauti and K. Miyosi.

The present study was done to know the direction of a group taken on passing the end of a wall after moved along it. Some number of a kind of fish was put in a tank and a projecting wall (Fig. 1, 2) was set on the one side of the tank (Fig. 1, 1). Among groups moving about in the tank the following two kinds of movement were observed:

(1) To move along the projecting wall and *curve out* on passing the end of the wall Fig. 1, 3–3–3).

(2) To move along the wall and *curve in* on passing the same (Fig. 1, 3–3–4).

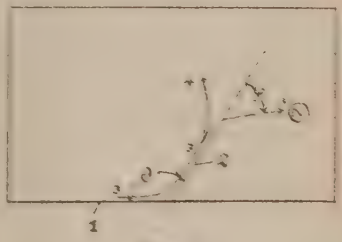


Fig. 1.

Table. I.

Fish: Carp 3~9 cm, Tank: 2.7 m × 1.8 m, No. of fishes: 25~100.

$\theta°$	$l$cm.	$\varphi°$ / N	Number of groups. curve out 0~45	45~90	90~135	135~180	curve in
30.0	85	0~10	6	10	40	44	5
		10~20	0	1	0	3	
		20~30	0	0	0	2	
		30~40	0	0	3	1	
45.0	"	0~10	3	34	55	51	20
		10~20	3	7	13	13	
		20~30	2	5	12	9	
70.0	"	0~10	5	13	57	63	15
		10~20	1	3	11	13	
		20~30	4	10	13	19	
		30~40	4	5	11	16	
90.0	"	0~10	88	229	332	111	65
		10~20	15	49	77	29	
		20~30	12	36	41	18	
		30~40	4	28	21	25	
		40~	3	8	8	6	
110.0	"	0~10	12	50	77	8	7
		10~20	3	10	20	5	
		20~30	3	18	17	2	
		30~40	1	13	13	2	
135.0	"	0~10	6	63	31	1	23
		10~20	5	38	6	2	
		20~30	3	34	11	1	
150.0	"	0~10	3	86	21	0	4
		10~20	4	16	3	1	
		20~30	0	12	3	0	
		30~40	1	6	6	0	

$\theta°$	$l$cm.	$\varphi°$ / N	Number of groups. curve out 0~45	45~90	90~135	135~180	curve in
30.0	45	0~10	0	0	2	2	0
		10~20	0	1	0	0	
		20~30	1	0	0	0	
45.0	"	0~10	0	6	14	13	0
		10~20	0	0	1	3	
		20~30	0	0	0	1	
90.0	"	0~10	7	32	71	20	17
		10~20	4	10	13	0	
		20~30	2	11	7	1	
		30~40	4	5	14	3	
135.0	"	0~10	2	15	9	0	8
		10~20	0	9	3	0	
		20~30	1	3	1	0	
		30~40	0	1	0	0	
150.0	"	0~10	5	20	2	0	6
		10~20	1	4	0	0	
		20~30	1	1	0	0	
22.5	85	0~30	53	74	101	96	32
45.0	"	"	31	61	97	70	33
67.5	"	"	21	53	118	58	45
90.0	"	"	43	151	167	60	62
112.5	"	"	18	72	109	16	31
135.0	"	"	18	125	40	26	16
157.5	"	"	12	109	79	21	57

The movement of group barred from its course by the projecting wall may be affected by its length, l, and the angle, θ, between that wall and the side along which the group moved, and the size[1] of the group, N. So the direction in which the group moves on passing the end of the wall and the size of the group were recorded for different values of θ and l.

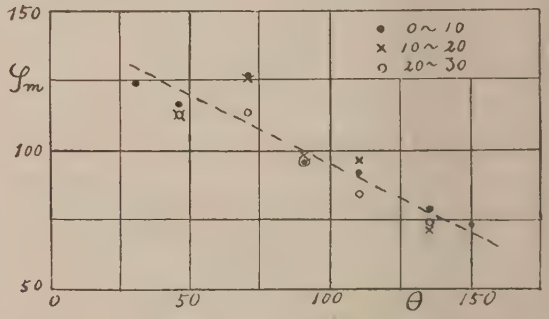
Table I shows the result of experiment. In this table φ denotes the angle between the produced line of the projecting wall and the direction in which the group moves on passing the end of that wall.

We calculate the mean direction, φ_m (i. e. mean value of φ), taken by groups which *curve out* on passing the end of the projecting wall when the length of the wall is 85 cm. and get the result as given in Table II. The relation between φ_m and θ in Table II is shown in Fig. 2.

Table. II

$\theta°$	N	$\varphi°_m$
30	0~10	124.5
45	0~10	115.5
〃	10~20	112.5
〃	20~30	112.5
70	0~10	125.8
〃	10~20	125.2
〃	20~30	113.8
90	0~10	95.3
〃	10~20	97.2
〃	20~30	95.4
110	0~10	92.6
〃	10~20	96.6
〃	20~30	84.8
135	0~10	79.5
〃	10~20	72.0
〃	20~30	74.6
150	0~10	73.8

Fig. 2.



From Fig. 2 we learn that the relation between θ and φ_m is linear when $\theta=30°\sim150°$, and the size of group has no effect on this relation.

Hence, from Table I we calculate the mean direction φ_m irrespective of the size of group and get the result as given in Table III. Fig. 3 shows the relation between φ_m and θ in Table III.

From Fig. 3 we learn that the length of wall has no effect on the relation between θ and φ_m.

Next, from Table I we calculate the percentage of number of groups which have a definite value of φ against the total number of groups which *curve out* on passing the end of projecting wall in cases the values of θ are 22°.5~45°.0, 67°.5~70°.0, 90°.0~112°.5 and 135°.0~157°.5 respectively and we get Table IV. Fig. 4 shows the relation of that percentage to the value of φ.

(1) By the size of group the writers mean the number of f h of that group.

Table. III.

φ'	δ_m	v'_m
30.0~45.0	45	122.6
45.0~	/	97.5
135.0~135.0	/	90.5
30.0~	85	123.4
45.0~	/	108.3
90.0~	/	122.6
90.0~	/	95.4
225.0~	/	82.6
225.0~	/	90.2
250.0~	/	73.4

Fig. 3.

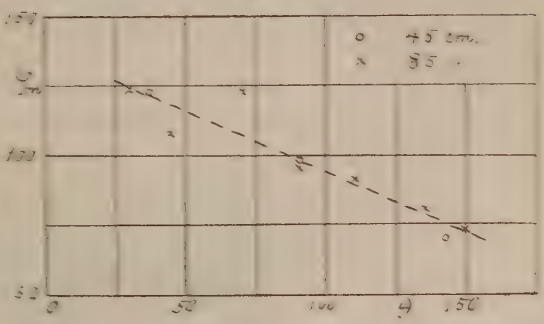
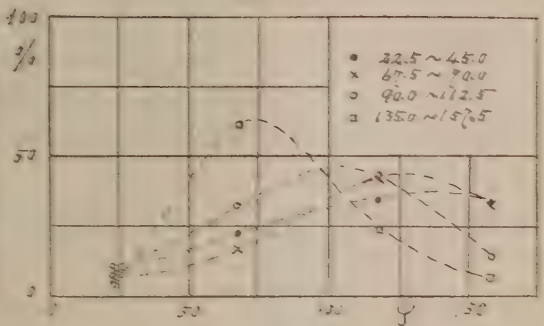


Table. IV.

δ=85 cm N=0~30

φ' \ v'	0~45	45~90	90~135	135~180
22.5~45.0	9.1	22.5	34.8	33.7
67.5~90.0	9.7	17.1	46.1	33.2
90.0~112.5	10.4	32.3	43.4	14.1
135.0~157.5	6.8	21.7	24.8	6.0

Fig. 4.



From Fig. 4 we know that the percentage has a maximum value for a definite value of φ and the maximum value of the percentage increases with δ, while the value of φ corresponding to the maximum percentage decreases as δ increases.

Calculating the ratio of the number of groups from Table I which *curve in*, to number of groups which *curve out*, we get Table V.

Table. V.

φ'	The ratio of the number of groups which *curve in* to the number of groups which *curve out*
22.5~30.0	8.3
45.0	15.4
67.5~90.0	12.5
90.0	10.3
112.5~135.0	8.0
135.0	5.8
157.5~180.0	15.9

Table V shows that the influence of δ upon the ratio, just referred to, is not remarkable.

Before closing the paper we should like to express our thanks to Mr. M. Kawajiri, who gave many facilities for the experiment.

Sept., 1927. Physical laboratory, Imp. Fisher. Inst. Tôkyô.

ON THE MOVEMENT OF A FISH-GROUP. II.

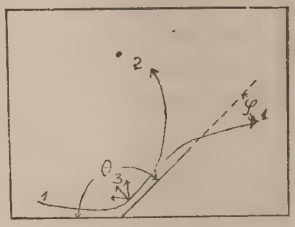
THE CASE WHEN FISHES WERE BARRED FROM THEIR PROGRESS BY A WALL.

By

Dr. M. Tauti and T. Hudino.

The present study was made to know how a fish-group alters it's course when it is barred from it's progress by a wall. When a group moving along one side of a pond meets with a wall projecting from that side, the group will take any one of the following three movements.

Fig. 1.



(1) To move along the wall and *curve out* on passing the end of the wall (Fig. 1, 1–1).

(2) To move along the wall and *curve in* leaving the wall (Fig. 1, 1–2).

(3) To *disperse* in the vicinity of the base of the projecting wall (Fig. 1, 1–3).

[I] The case when a group is not influenced by others.

The movement of group barred from it's course by a wall may be affected by the length of wall, the size[1] of group and the angle, θ, between that wall and the side along which the group moves. Tauti and Miyosi[2] ascertained that the effect of length of wall and the size of group is neglisible. So in the present study, neglecting the effect of length of wall and the size of group, we tried to know the influence of the angle, θ, upon the number of group of three kind of movements just above stated and also upon the direction in which the group *curves out* on passing the end of the projecting wall. Table I gives the results of experiment on a group of "*Ugui*" (*Leuciscus hakuensis* Günther).

(1) By the size of group the writers mean the No. of fish of that group.

(2) M. Tauti and K. Miyosi:—On the movement of a fish-group. I. On the direction of a fish-group on passing the end of a wall along which it has moved. (This Journal pp. 73-76).

In this table φ denotes the angle between the produced line of the projecting wall and the direction in which the group moves on passing the end of that wall. (See Fig. 1.).

From Table II (a) calculated from Table I. we know that the rate of number of *curve out* to the total number of groups decreases as θ increases, but the rate of *curve in* and that of *disperse* increase with θ.

Table. I.

Fish: "Iwashi" 3 cm. in length. Tank: 1.8 m × 1.2 m. Projecting wall: 91 cm. in length.

Number of groups

$\varphi°$ / $\theta°$	*curve out*				*curve in*	*disperse*
	0–45	45–90	90–135	135–180		
45	174	303	124	18	79	98
90	229	339	148	12	113	121
135	196	182	44	2	213	247

Table. II.

(a)

$\theta°$	45	90	135
curve out %	78	67	48
curve in "	10	11	24
disperse "	13	21	28

(b)

$\theta°$	45	90	135
$\varphi_m°$	66	61	52

Table II (b) calculated from Table I shows that φ_m – mean value of φ – decreases as θ increases. This result agrees with that obtained by Tauti and Miyosi[1].

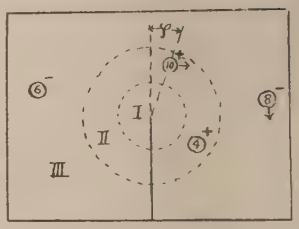
(4) The case when a group is influenced by others.

A group just to curve out may be attracted by another group swimming about near the end of the projecting wall. And the attracting power may be affected by the size and position (the distance from the end of wall and the angle φ') of the *attracting* groups. In order to know those effects we took the following method: *Attracting* groups were recorded with symbols ○ (for *resting*) and ○→ (for *moving*) in the corresponding positions, with the size of the *attracting* groups represented in numerals of the number of fishes of each group. And, if a group just to curve out advanced toward one of *attracting* groups, mark + was

(1) *op. cit.*

put in addition to the symbol of that group and mark − to the symbols of all others, as shown in Fig. 2.

Fig. 2.



In the first place, we calculate the rate of number of symbols with + sign to the total number, irrespective of position and movement in cases the sizes are 1–10, 11–20 and 21–30 respectively. Table III (a) shows the result of calculation. From that table, we know that the attracting power increases with the size of *attracting* group.

In the second place, we calculate the rate of number of symbols with + sign, irrespective of size, distance and movement, in cases the values of φ are 0°–45,° 45°–90,° 90°–135° and 135°–180° respectively. The result may be seen from Table III (b). This table shows that the attracting power increases as the value of φ decreases.

In the third place, we draw two concentric circles whose centre is at the end of the projecting wall and whose radii are $\frac{1}{3}$ and $\frac{2}{3}$ of the length of wall, and we divide whole *attracting* groups into the following three classes :— the position of *attracting* group lies (I) in the inner circle, (II) between the inner and outer circles and (III) outside of the outer circle. Then we calculate the rate of number of symbols with + sign as shown in Table III (c). Table III (c) shows that the attracting power increases as the distance of the *attracting* group from the end of wall diminishes.

Table III (d) gives the rate of number of symbols with + sign in the cases of *moving* and *resting*. From this table, we know that *moving* groups sometimes have stronger effect than *resting* ones.

Table. III.

(a) Effect of size.

"*Koi*" (Carp)				"*Ugui*" (*Leuciscus hakuensis*)				
Size	1–10	11–20	21–30	Size	1–3	4–6	7–9	10–20
No. of symbols with +	271	89	43	No. of symbols with +	38	38	12	6
with −	1766	225	85	with −	406	614	186	72
% of +	13	28	34	% of +	9	6	6	8

(b) Effect of direction.

"*Koi*"					"*Ugui*"				
φ°	0–45	45–90	90–135	135–180	φ°	0–45	45–90	90–135	135–180
No. of symbols with +	149	175	109	32	No. of symbols with +	26	30	23	
with −	457	777	905	869	with −	262	261	287	236
% of +	24	18	11	4	% of +	9	10	7	

(c) Effect of distance.

"*Koi*" Tank : 1.8 m × 2.7 m
Projecting wall : 91 cm in length

Position	I	II	III
No. of symbols with +	53	50	302
with −	44	124	2145
% of +	59	29	12

"*Ugui*" Tank : 1.8 m × 2.7 m
Projecting wall : 91 cm in length
No. of groups *curving out* : 311

Position	I	II	III
No. of symbols with +	43	38	1
with −	45	208	795
% of +	49	15	0

Tank : 5.5 m × 5.5 m
Projecting wall : 180 cm in length
No. of groups *curving out* : 326

Position	I	II	III
No. of symbols with +	12	29	19
with −	6	58	633
% of +	67	33	3

(d) Effect of movement.

"*Koi*"

	moving	*resting*
No. of symbols with +	379	86
with −	1483	1525
% of +	20	5

"*Ugui*"

	moving	*resting*
No. of symbols with +	63	19
with −	703	343
% of +	8	4

Calculating percentage of total number of symbols with + sign against the number of groups *curving out* and rate of total number of *approaching* groups to the number of groups *curving out*, we get the results as shown in Table IV.

Table. IV.

	No. of *approaching* groups / No. of groups *curving out*	No. of symbols with + sign / No. of groups *curving out*
"*Koi*"	2.4	18%
"*Ugui*"	3.6	20%

In the case of "*Koi*", 2.4 groups swim about at any time near the end of projecting wall and only 18% of groups *curving out* moves toward one of them. In the case of "*Ugui*" only 20% of groups *curving out* moves toward one of 3.6 groups swimming about near the end. Therefore we may say that the influence of a group upon the movement of another is not so strong as we imagined before the study.

In conclusion, we should like to express our gratitude to Mr. M. Kawajiri who afforded many facilities for the experiment.

Sept., 1928 Physical laboratory, Imp. Fish. Inst. Tōkyō.

ON THE MOVEMENT OF A FISH-GROUP. III.

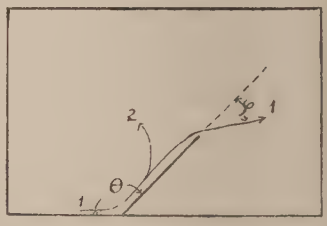
THE CASE WHEN FISHES WERE BARRED FROM THEIR PROGRESS BY A NET.

By

Dr. M. Tauti and H. Yasuda.

Tauti and Miyosi[1] studied on the direction taken by groups of "*Koi*" (Carp) when they pass the end of a wall projecting from one side of a pond after having moved along that side and the wall, and obtained the following results: (i) When φ denotes the angle between the direction taken by groups which *curves out* on passing the end of the projecting wall and the produced line of wall (Fig. 1, 1-1), φ_m—the mean value of φ—decreases as θ increases. (ii) If $p\%$ of the total number of groups which *curue out* on passing the end of wall will take the direction of φ, there is one of the value of φ, φ_{max}, which gives, p_{max}, the maximum value of p. p_{max} increases but φ_{max} decreases as θ increases. (iii) The ratio of the number of groups which *curve in* leaving the wall (Fig. 1,1-2) to that of groups which *curve out* on passing the end of wall is not affected upon by the value of θ. (iv) The effect of the length of wall and that of the size of group upon the relation (i) are neglisible.

Fig. 1.



Tauti and Hudino[2] ascertained that the relation (i) holds good for groups of "*Ugui*" (*Leuciscus hakuensis*). They also studied how much fraction of the groups having moved along the side *disperses* in the vicinity of the base of the projecting wall, or alters the course and moves along the wall and *curves in* leaving the wall, or again *curves out* on passing the end of wall, and found that the number of groups which *curve out* decreases as θ increases but the number of *curve in* and *disperse* increase with θ.

We made an experiment to know how the relation above mentioned is modified in the case of a net-wall.

(1) M. Tauti and K. Miyosi:— On the movement of a fish-group. I. On the direction of a fish-group on passing the end of a wall along which it has moved. (This Journal, pp 73-76).

(2) M. Tauti and T. Hudino:— On the movement of a fish-group. II. The case when fishes were barred from their progress by a wall. (This Journal, pp 76-79).

Two aquariums (1.8 m × 1.2 m and 2.7 m × 1.8 m) and a pond (5.4 m × 3.6 m) were used, and a net-wall, which was a little shorter than half of the shorter-side of an aquarium or pond, was set to project from the longer-side holding an angle, θ, between the side and net-wall. And the size and course of group were recorded on "*Medaka*" (*Oryzias latipes*), "*Koi*" (Carp), "*Nizimasu*" (Rainbow trout) and "*Ugui*" (*Leuciscus hakuensis*).

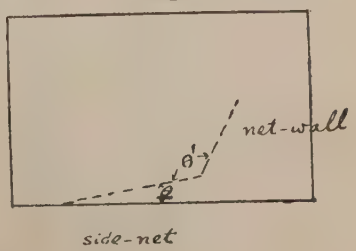
The result of this experiment may be summarized in Table I.

Table. I.
Number of groups.

	θ° \ φ°	*curve out*				*curve in*	*disperse*
		0~45	45~90	90~135	135~180		
"*Medaka*" 2.5~4.0 cm	22.5	11	19	62	21	53	55
	45.0	3	4	28	11	60	25
	67.5	2	20	108	8	7	25
	90.0	6	35	76	23	8	18
	112.5	0	100	42	5	0	0
	135.0	4	111	11	0	9	2
	157.5	14	90	11	0	5	3
"*Koi*" 4.5~7.5 cm	30.0	13	102	112	8	45	135
	60.0	27	113	136	3	41	120
	90.0	17	283	26	0	62	46
	120.0	31	357	25	0	32	24
	150.0	70	244	28	2	34	21
"*Nizimasu*" 3.0~5.5 cm	30.0	3	69	34	0	26	70
	60.0	2	61	58	1	20	60
	90.0	54	124	5	0	27	20
	120.0	43	125	6	0	17	27
	150.0	74	109	6	0	31	10
"*Nigimasu*" 13.5~23.0 cm	30.0	6	40	64	8	22	46
	60.0	11	75	31	0	37	56
	90.0	29	91	14	0	35	37
	120.0	19	89	6	0	26	22
	150.0	47	106	4	0	27	8
"*Ugui*" 16.5~19.5 cm	30.0	4	79	51	1	15	52
	60.0	9	96	48	0	18	40
	90.0	9	109	14	0	33	38
	120.0	16	128	21	0	13	3
	150.0	40	81	7	0	6	7

Next, a net which is a little shorter than half the length of the longer-side of aquarium was set to project from one side of the aquarium with angle, θ. This net we call, for convenience, *side-net*. (See Fig. 2). Another net of about half the length of the shorter-side was fixed to the free end of the *side-net* holding an angle, θ', between these two nets. By this arrangement

Fig. 2.



we studied to get similar records as Table I.

Table II shows the result obtained.

Table II.

Number of groups.

	$\theta°$	$\varphi°$ / $\theta'°$	*curve out* 0~45	45~90	90~135	135~180	*curve in*	*disperse*
	113.0	22.5	1	14	43	14	23	110
	168.0	45.0	0	9	66	44	15	72
"*Medaka*"	81.0	67.5	0	7	85	38	22	43
2.5~4.0 cm	90.0	90.0	1	30	98	14	19	61
	72.0	112.5	0	20	110	18	22	33
	79.5	135.0	0	42	90	8	19	28
	78.5	157.5	3	103	80	4	7	2
	90	30	28	156	126	8	41	112
	〃	60	11	163	114	2	36	100
"*Koi*"	〃	90	51	253	23	0	42	50
4.5~7.5 cm	〃	120	62	278	9	0	26	19
	〃	150	132	180	17	0	14	15
	90	30	21	56	21	4	29	65
	〃	60	41	66	40	1	25	41
"*Nizimasu*"	〃	90	50	112	4	0	28	45
3.0~5.5 cm	〃	120	33	114	21	0	24	16
	〃	150	107	68	1	0	17	13

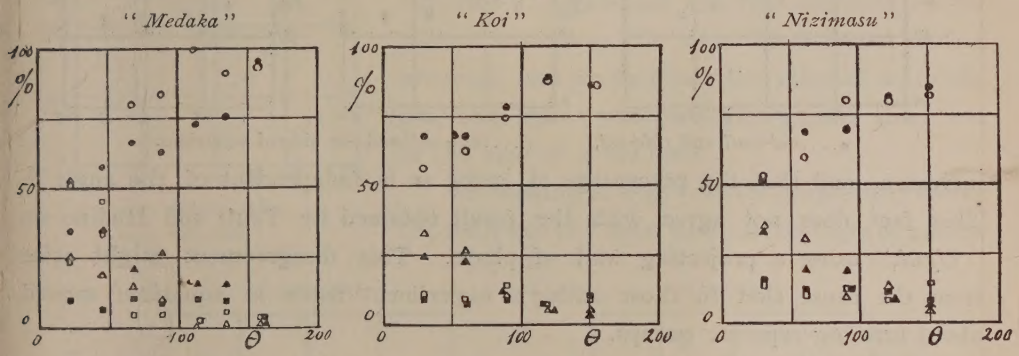
Table. III.

Percentage of number of groups.

	net-wall and one side of aquarium.				*net-wall* and *side-net.*			
	$\theta°$	*curve out*	*curve in*	*disperse*	$\theta'°$	*curve out*	*curve in*	*disparse*
	22.5	51	24	25	22.5	35	11	54
	45.0	34	46	19	45.0	58	7	35
"*Medaka*"	67.5	81	5	15	67.5	67	11	22
2.5~4.0 cm	90.0	85	5	11	90.0	64	9	27
	112.5	100	0	0	112.5	73	11	16
	135.0	92	7	1	135.0	75	10	15
	157.5	94	4	2	157.5	96	4	1
	30	57	11	33	30	68	9	24
"*Koi*"	60	63	9	27	60	68	8	23
4.5~7.5 cm	90	75	14	11	90	78	10	12
	120	88	7	5	120	89	7	5
	150	86	9	5	150	86	11	4
	30	53	13	35	30	52	15	39
"*Nizimasu*"	60	60	10	30	60	69	12	19
3.0~5.5 cm	90	80	12	9	90	70	12	19
	120	80	8	12	120	81	11	8
	150	82	13	5	150	85	8	6
	30	64	12	25				
"*Nizimasu*"	60	56	18	27				
18.5~23.0 cm	90	65	17	18				
	120	71	16	14				
	150	82	14	4				
	30	67	7	26				
"*Ugui*"	60	73	9	19				
16.5~19.5 cm	90	65	16	19				
	120	91	7	2				
	150	91	4	5				

From Tables I and II, we calculate the percentages of the number of groups which *curve out*, *curve in* and *disperse* against the total number of groups and also calculate the mean value of φ, φ_m. The results are given in Tables III and IV, Figs. 3 and 4.

Fig. 3.



●..*curve out*, ■..*curve in*, ▲..*disperse* in the case of *side-net* and *net-wall*
○.. " , □.. " , △.. " in the case of *net-wall* and one side of aquarium.

Table IV.

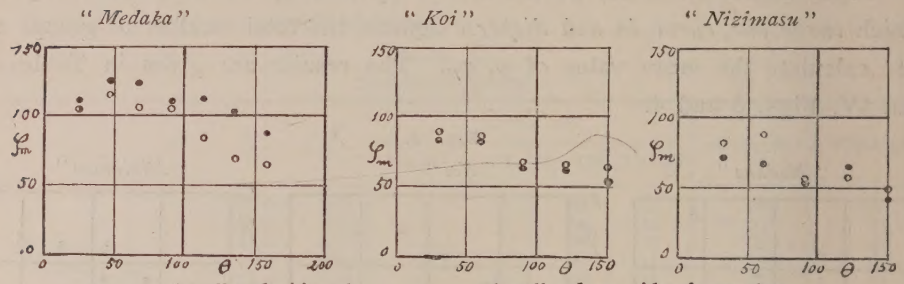
Mean direction of *curve out*

	net-wall and one side of aquarium		*net-wall* and *side-net*	
	$\theta°$	$\varphi°_m$	$\theta'°$	$\varphi°_m$
"*Medaka*" 2.5~4.0 cm	22.5	105	22.5	111
	45.0	113	45.0	126
	67.5	107	67.5	123
	90.0	105	90.0	110
	112.5	83	112.5	112
	135.0	70	135.0	102
	157.5	66	157.5	88
"*Koi*" 4.5~7.5 cm	30	90	30	84
	60	86	60	84
	90	69	90	64
	120	67	120	61
	150	63	150	52
"*Nizima u*" 3.0~5.5 cm	30	81	30	71
	60	89	60	68
	90	55	90	55
	120	58	120	64
	150	51	150	40
"*Nizimasu*" 13.5~23.0 cm	30	96		
	60	75		
	90	61		
	120	62		
	150	55		
"*Ugui*" 16.5~19.5 cm	30	84		
	60	79		
	90	69		
	120	69		
	150	52		

Looking at Fig. 3, we know that the percentages of *curve out*, *curve in* and *disperse* make no difference, whether the corner at which the groups alter their course to move along the *net-wall* is constructed by the *side-net* and *net-wall* or the *net-wall* and one side of aquarium.

Table III and Fig. 3 show that on "*Medaka*," "*Koi*," "*Nizimasu*" and "*Ugui*," the percentage of groups *curving out* increases but that of groups *dispersing* decreases as θ

Fig. 4.



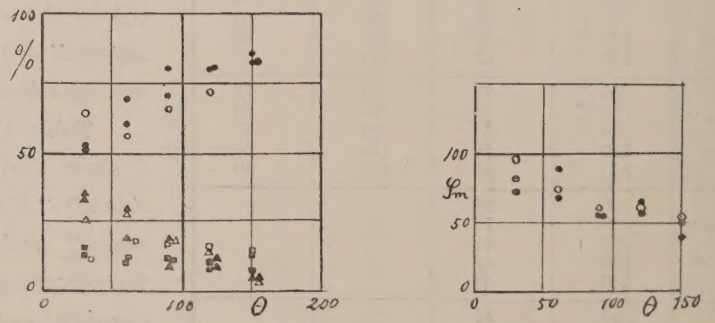
●....*net-wall* and *side-net*, ○....*net-wall* and one side of aquarium.

increases, and that the percentage of *curve in* is independent of the angle θ. This fact does not agree with the result obtained by Tauti and Hudino on "*Ugui*," using a projecting wall of plank. This disagreement might arise from the cause that in those author's experiment fishes in aquarium moved about forming separate groups.

Table IV and Fig. 4 show that φ_m decreases as θ increases in the case of groups of "*Medaka*," "*Koi*," "*Nizimasu*" and "*Ugui*," whether the corner where the groups alter their course is made of net or net and one side of aquarium. That φ_m decreases as θ increases agrees with the result obtained by Tauti and Miyosi[1] using a projecting *plank-wall* on group of "*Koi*," and also agrees with that obtained by Tauti and Hudino[2] using a *plank-wall* on groups of "*Ugui*."

Next, to know what effect has the difference in the age of fishes upon the percentages of the groups as well as upon the value of φ_m, we draw Fig. 5 from Tables III and IV.

Fig. 5.

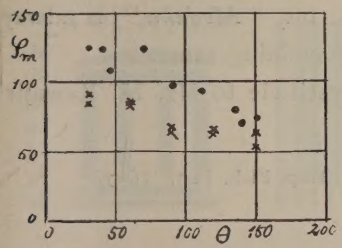


●..*curve out*, ■..*curve in*, ▲..*disperse* on "*Nizimasu*" 3.0~5.5 cm.
○.. 〃 , □.. 〃 , △.. 〃 on 〃 13.5~23.0 cm.

(1) (2) *op. cit.*

Fig. 5 shows that on "*Nizimasu*," the size of fishes has no effect upon these percentages and value of φ_m.

Fig. 6.

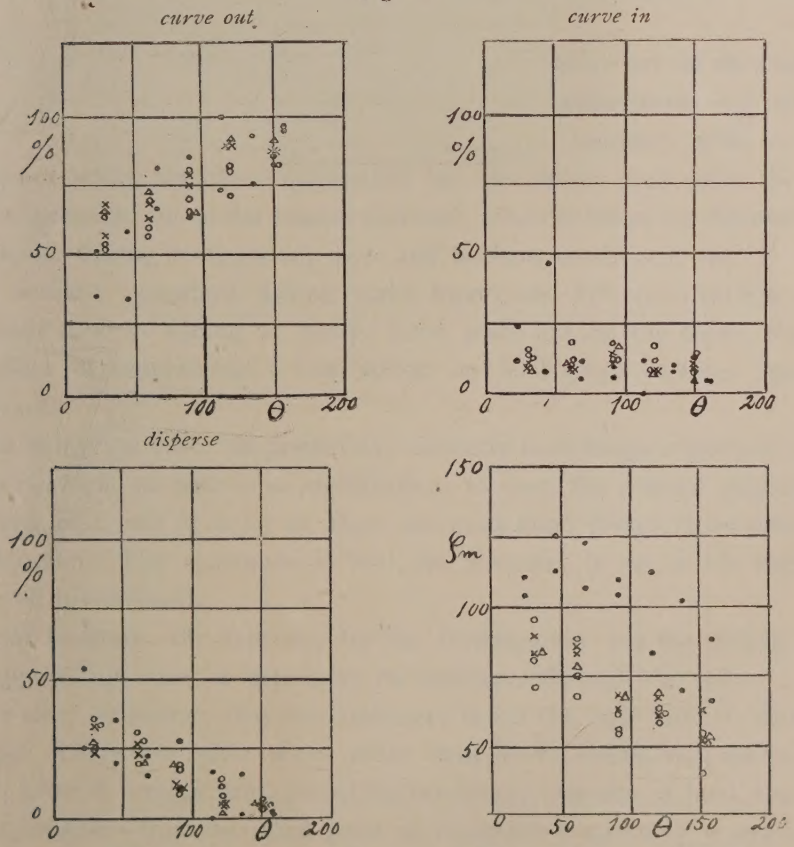


●....*plank-wall*
×....*net-wall*

In Fig. 6, we can compare the value of φ_m obtained by Tauti and Miyosi[1] on "*Koi*" barred with a *plank-wall* and that obtained by the present writers on the same fishes barred with a *net-wall*, and we find that the value of φ_m in the case of a *plank-wall* is always greater than that in the case of a *net-wall*.

On looking at Fig. 7 which graphically shows the influence of θ upon those percentages of groups

Fig. 7.



●...."*Medaka*", ×...."*Koi*", ○...."*Nizimasu*", △...."*Ugui*"

(1) *op. cit.*

and upon φ_m given in Tables III and IV, we may say that the relation of those percentages to the value of θ is same for "*Medaka*," "*Koi*," "*Nizimasu*" and "*Ugui*" and that the relation between θ and φ_m is same for "*Koi*," "*Nizimasu*" and "*Ugui*" but the value of φ_m for "*Medaka*" is always greater than that for the other kinds of fishes, θ remaining same.

In conclusion, we should like to express our gratitude to Mr. M. Kawajiri, who afforded many facilities for this experiments.

Oct., 1928 Physical laboratory, Imp. Fish. Inst., Tôkyô.